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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION
BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 19

Current Aeromedical Issues in Rotary Wing Operations

(Problèmes actuels de médecine aéronautique posés par les opérations utilisant des voilures tournantes)

Papers presented at the RTO Human Factors and Medicine Panel (HFM) Symposium held in San Diego, USA, 19-21 October 1998.

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The Research and Technology Organization (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by 7 Panels, dealing with:

• SAS	Studies, Analysis and Simulation
• SCI	Systems Concepts and Integration
• SET	Sensors and Electronics Technology
• IST	Information Systems Technology
• AVT	Applied Vehicle Technology
• HFM	Human Factors and Medicine
• MSG	Modelling and Simulation

These Panels are made up of national representatives as well as generally recognised 'world class' scientists. The Panels also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Current Aeromedical Issues in Rotary Wing Operations

(RTO MP-19)

Executive Summary

The Human Factors and Medicine Panel held a Symposium on current aeromedical problems arising from helicopter operations, in San Diego, in the United States from 19th to 21st October 1998.

The use of helicopters is not restricted to a single branch of the armed forces, as they are deployed by Navies, Armies and Air Forces. Their use may be specific to one of the Services but many of the problems encountered are common to all users. Moreover, there has been an expansion of the civilian helicopter fleet, which means that military users will increasingly be able to benefit from the experience acquired in this domain. We can summarise this type of use as follows: standard means of transport, or for medical evacuation, land or sea surveillance, ground attack and, more recently, for air defence. However, the performances achieved by helicopters and their flight control equipment enable crews to operate in more hostile conditions (poor weather) or to carry out low-level night combat operations (use of night vision goggles or helmet mounted displays). Given its characteristics and the complexity of its use and its environment, the helicopter is exposed to damage and a whole series of measures can be previewed to alienate this risk. The presentations concentrated on five main topics: 1) Crew training, 2) The different conditions of use, 3) The psycho-physiological component, 4) Survival equipment and methods, 5) Accidents and their prevention.

This symposium was of great interest to the military, owing to the inclusion of the following subjects:

- a summary assessment of the constraints specific to missions carried out by helicopter crews and the means of dealing with them,
- crew selection and training,
- the highlighting of accident-producing factors such as spatial disorientation and the usefulness of preventive measures such as tactile stimulators and simulators,
- the use of CRM (crew resource management) for dealing with critical situations,
- indications as to the use of the helicopter, its equipment and the type of crew, depending on the type of evacuation to be performed as part of integrated medical relief operations and the measures to be taken in the event of accidents involving large numbers of wounded and, as a result, varied and complementary evacuation facilities,
- the complexity of combat RESCO,
- dynamic (vibration) and psycho-physiological stress and the pathological consequences such as fear and dorsalgia,
- the use of new head-mounted equipment (visor display) or NBC equipment with their benefits but also the additional constraints which they impose,
- the limits of personal flight and safety equipment, the need to improve it and to train aircrew in its use,
- the epidemiological analysis of accidents, of their causes and of the ways of limiting injuries (absorbent structure, fuel tank protection systems, anti-crash seats) “airbags” or even special devices for use when the helmet is weighted by equipment).

A careful reading of the papers presented at the symposium will enable both specialists and decision-makers to make a summary assessment of the constraints of the missions on the one hand, and on the other, of the new methods of protection and training and the new technologies which will enable aircrew to carry out their missions in a safer environment. In addition, they will perhaps discover that helicopter operation can be optimised by a series of different devices and above all by judicious matching of “type of helicopter - type of aircrew training - type of additional on-board equipment”.

Problèmes actuels de médecine aéronautique posés par les opérations utilisant des voilures tournantes

(RTO MP-19)

Synthèse

Le panel de médecine et des facteurs humains a organisé un symposium sur les problèmes actuels de médecine aéronautique posés par les opérations utilisant des voilures tournantes à San Diego, Etats-Unis du 19 au 21 octobre 1998.

L'utilisation de l'hélicoptère n'est pas propre à une seule arme puisqu'on le retrouve aussi bien dans l'armée de l'air que dans la marine et l'armée de terre. Son utilisation peut être spécifique à l'arme mais de nombreux problèmes sont communs. De plus, on assiste à une expansion de la flotte d'hélicoptères dans le milieu civil qui permettra de plus en plus au milieu militaire de bénéficier de cette expérience. Cette utilisation peut être schématiquement présentée de façon suivante : moyen de transport standard ou dans le cadre d'évacuation sanitaire, surveillance terrestre ou maritime, attaque au sol et depuis peu défense aérienne. Par contre, les performances des hélicoptères et des équipements pilotes permettent aux équipages d'intervenir dans des conditions de vol plus hostile (météo dégradée) ou d'assurer des missions de nuit en vol basse altitude et dans le cadre du combat (utilisation de jumelles de vision nocturne ou viseur visuel de casque). Par ses caractéristiques et la complexité de son utilisation ou de son environnement, l'hélicoptère peut être accidenté et toute une série de mesures peut être envisagée pour reculer ce risque. Les présentations ont porté sur cinq thèmes principaux : 1) L'entraînement des équipages, 2) les différentes conditions d'utilisation, 3) la composante psycho-physiologique, 4) les équipements ou les méthodes de survie, 5) les accidents et leur prévention.

Pour les militaires, ce symposium a représenté un grand intérêt en raison des sujets suivants :

- un bilan des contraintes spécifiques aux missions menées par les équipages d'hélicoptères et les moyens d'y faire face,
- la sélection et l'entraînement des équipages,
- la mise en évidence des facteurs accidentogènes tel que la désorientation spatiale et l'intérêt de mesures préventives pour y remédier tel que des stimulateurs tactiles et l'utilisation de simulateur,
- l'intérêt de la CRM (crew resource management) pour faire face aux situations critiques,
- l'indication de l'utilisation de l'hélicoptère, de son équipement et du type d'équipage en fonction du type d'évacuation dans le cadre de secours médicaux intégrés et les mesures à prendre dans le cas d'accidents impliquant de très nombreux blessés et donc des moyens d'évacuation variés et complémentaires,
- la complexité de la RESCO de combat,
- la contrainte dynamique (vibration) et psycho-physiologique et les conséquences pathologiques telles que la peur et les dorsalgies,
- l'utilisation des nouveaux équipements de tête (viseur visuel de casque) ou d'équipements NBC avec leur intérêt mais aussi les contraintes supplémentaires qu'ils imposent,
- les limites des équipements personnels de vol et de secours, la nécessité de les améliorer et d'entraîner les équipages à leur utilisation,
- l'analyse épidémiologique des accidents, des causes, des moyens pour limiter les blessures (structure absorbante, système de protection des réservoirs, siège anti-crash, «airbags» voire même dispositifs spéciaux lors de l'utilisation de casques alourdis par les équipements).

Une lecture attentive des communications du symposium permettra aussi bien aux décideurs qu'aux experts de faire un bilan concernant les contraintes des missions, des nouvelles méthodes de protection ou d'entraînement ou des nouvelles technologies permettant aux équipages d'assurer leurs missions dans un environnement plus sécurisé. Par ailleurs, cette lecture leur permettra peut-être de découvrir que l'utilisation de l'hélicoptère peut être optimisée par une série de dispositifs et surtout par l'adéquation «type d'hélicoptère - type d'entraînement de l'équipage - type d'installation complémentaire à bord».

Contents

SESSION I: TRAINING FOR HELICOPTER OPERATIONS

SESSION II: ROTORCRAFT OPERATIONS UNDER DIFFERENT CONDITIONS

SESSION III: PSYCHO-PHYSIOLOGICAL ASPECTS IN ROTARY-WING OPERATIONS

SESSION IV: HUMAN FACTORS AND LIFE SUPPORT EQUIPMENT

SESSION V: ROTORCRAFT ACCIDENT AND CRASHWORTHINESS

Preface

Rotary wing operations include transport of passengers and wounded in the military and civilian arenas, as well as combat mission. New equipment and new technologies are increasingly permitting to expand the domain of rotary wing activities, and numerous new types of helicopters may be used in a wide range of flying conditions (overcast, night,...). This report focuses on aeromedical aspects of human factors, flight medicine, standardization and interoperability issues. Analysis of past experiences permits to better design emerging technologies for improving crew safety and efficiency. Specialists working in the domain will find this report the most up-to-date information concerning:

- Crew training for helicopters operations
- The use of helicopters in extreme mission environments
- Human factors and psychophysiology
- Life support equipment, accident and crashworthiness.

Human Factors and Medicine Panel

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TECHNICAL EVALUATION REPORT

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1. INTRODUCTION

The Human Factors and Medicine Panel (HFM) held a Symposium on " CURRENT AEROMEDICAL ISSUES IN ROTARY WING OPERATIONS" at the Conference Room of the Westgate Hotel, San Diego, California, USA, 19th-23rd October 1998. Forty-four contributed papers were presented along with a keynote address. Eight NATO nations contributed to the main programme.

2. THEME

The theme of the Symposium was to introduce, exchange and discuss practical, theoretical and conceptual experience in rotary wing operations. This topic has not been discussed for a long period of time. New developments in rotary wing technologies and trends in this particular area of the Aviation Medicine made it necessary to review the major aeromedical and human factor problems.

3. PURPOSE AND SCOPE

This Symposium has examined the technical and aeromedical aspects of human factors and flight medicine, with particular focus on standardisation and inter-operability.

The scientific programme has covered a wide range of experience in the overall operation of helicopters for general utility purposes, for military operations over water and over land, for search and rescue, aeromedical evacuation particularly under hazardous conditions.

This includes new topics in training for helicopter operations, psycho-physiological aspects in rotary wing operations, human factors and life support equipment and rotorcraft accident and crashworthiness.

The final purpose of the symposium is to enhance mission efficiency of military and civilian rotary wing operations and improve flight safety, thus saving lives and money.

4. SYMPOSIUM PROGRAM

The Symposium consisted of a keynote address on the " Challenge of command and control of helicopters in military operations" , presented by General de Division C.H. de Monchy, Chief of the French Army Aviation, COMALAT, Villacoublay, FRANCE, and five Scientific Sessions which were chaired as follows:

a. Session 1. Training for helicopters operations. Med. en Chef J.M. Clère (FR) and Dr. F. Rios Tejada (SP).

b. Session 2. Rotorcraft operations under different conditions. Dr. E. Roedig (GE) and Dr. C.J. Brooks (CA).

c. Session 3. Psycho-physiological aspects in rotary wing operations. D. F. Rios Tejada (SP) and Dr. E. Roedig (GE).

d. Session 4. Human factors and life support equipment. Dr. CJ Brooks (CA) and Dr. E. Roedig (GE).

e. Session 5. Rotorcraft accident and crashworthiness. Dr. D. Shanahan (USA) and Med. en Chef J.M. Clère (FR).

Med. en Chef J.M. Clère and Maj. F. Rios Tejada acted as Symposium Chairmen.

5. TECHNICAL EVALUATION

In his keynote address General de Monchy warned of the complicated and difficult problems of Command and Control in his extensive experience with the French Army Aviation of helicopters deployed in operational settings. He noted that in modern helicopter factors such as advances in maneuverability, performance, all weather capabilities have played a significant part in operational tactical command and control in the final achievement of the mission.

SESSION 1. Training for helicopter operations.

The physiological requirements for a comprehensive training programme in the helicopter field were addressed in this Session.

The first paper (#1) was presented by Dr. Braithwaite on "Controlling the hazard of spatial disorientation (SD) in rotary-wing operations by enhanced training". He pointed out that SD still continues to be an important source of attrition in helicopters and human life and contributes up to 30% of serious US Army helicopter mishaps. He presented various training initiatives established through an American Triservice Research Agency and the International Forum of WP 61 of the Air Standardization Coordinating Committee. He reviewed all aspects of existing training programmes, classroom instruction, ground-based demonstrations, training in both dedicated SD demonstrators and flight simulators, SD for special forms of flight and training the SD trainers. The results have been so successful that a training programme has been introduced at Fort Rucker.

Mr. Bohemier and co-workers presented the paper #2 on "High-fidelity survival training for ditched aircrew and passengers", where they reviewed the factors involved in underwater disorientation related to rate of downward acceleration during descent; speed of rotation in two axis seating facing forward; back and side; plus loss of visual cues and loss of gravitational cues. They described the physiological factors such as introducing water in oral and nasal cavities, hydrostatic pressure on the body, violent ingress of water in the fuselage, psychological effect, previous diving experience and many others that must be taken into account for training and improving egress. They described several models of simulators and scenarios where training will be crucial for improving survival rates.

In the third paper (#3) "De la théorie à la pratique: conception d'un cours CRM pour les équipages d'hélicoptères militaires", Dr. Grau and co-workers provided the experience of the development and on site utilization of a complete CRM programme specifically designed for aircrews of Puma and Super Puma Squadrons. The type of CRM chosen, methodology applied, operational aspects and aircrew training were the most relevant factors in order to get the proper product. On the other hand the programme must be flexible for coping with the daily problems of the aircrew, which provide appropriate and specific solutions for every obstacle found. This work means an extensive guideline has been developed for each particular setting of CRM that can be fully applied to other NATO forces using the same type of aircraft.

Mrs. Fonne and Mrs. Myhre in paper #4 discussed "A systems approach to selection and training of aircrew to the air ambulance service" where they dealt with regulatory commitments in developing criteria for selection and training of aircrew, involving all parts of the system. In addition they discussed the problems if the dedicated helicopter should be limited to aeromedical transportation or for other non-medical transport missions as well. Finally, the authors discussed the role of choosing a particular operational helicopter; the standards required for the crew according to the level and characteristics of their training, and training requirements; and the appropriate education/training programme, in which common standards, definition of the operational model, standards for training and selection and risk assessment and safety audit must be considered.

SESSION 2. Rotorcraft operations under different conditions.

In paper #5 entitled "Primary and secondary air medical transport in ambulance helicopters" Dr. E. Roedig made a complete review of the latest, medical principles, statistical data and types of medevac including primary aeromedical transport, secondary air medical transport, search and rescue and safety aspect of this topic. He stated that there is a need for objective standards and criteria in the civilian military AMTS, which may only be achieved after additional and extensive patient outcome studies in addition to cost-benefit analysis have been examined.

Capt. Baldanta in paper #6 "Current operational issues in the civil guard air service", described the organization of this unique service regarding the number and variety of missions that they should accomplished all over Spain, mostly related to security and civil protection. He described the major human factors they have to deal with and finally concluded with appropriate recommendations.

In paper #7 entitled "Utilization of helicopters during the Chernobyl accident" Maj. Gen. Masharovsky, reviewed the different types of missions accomplished by a wide variety of helicopters and emphasize certain aspects of the task developed by the aircrew among them, aerial radiation & temperature, blocking of radionuclides from the damaged reactor, evacuation of wounded people and washing down the territory which had high levels of radiation. Also he described the coordination structure used for the proper management and control of the helicopters assigned to the operation.

Paper number #8, entitled "British army helicopter casualty evacuation in Belize (1995-1996)" presented by LtCol. A.J. Eke, described the experience of British Army Medevacuation in the Belizean territory. Hostile environment in relation to weather, jungle and lack of infrastructures made the task very difficult. Accidents, bites, diving accident, surgical problems were most common reasons for medevac. Finally, she made recommendations coming from their experience related to appropriate type of helicopter to use, specific equipment, training, health standards and preventive measures.

LCdr P. Van Aggelen and co-authors in paper #9 entitled "Something new- All together! The Rotterdam HEMS perspective", demonstrated the efficiency of an integrated system of emergency care by using rotary wing aircraft in which highly specialized medical personnel are brought to the patient. They concluded that by using the Helicopter Emergency Medical System-HEMS, they improved the clinical knowledge and military aeromedical experience and they reached a better level of cost/efficiency of medevac.

In paper #10 entitled "Combat search and rescue in naval aviation: Adriatic experience" M.P.B. Sicard presented the complexity of search and rescue under a combat situation. Each rescue is specific and requires skilled personnel and enough airmobile resources to integrated all the requirements needed for accomplishing the mission. Coordination in the use of the equipment, helicopters and personnel is crucial during the operation itself. In addition to that he described the concept of the coding which is used for given information of the functional status of the aircrew doing the search.

Mr. R. TAYLOR gave paper #12 entitled "An analysis of the impact of chemical/biological warfare environments on aviation crewmember cockpit performance". In his paper he reviewed the problems linked with the chemical and biological warfare environment related to certain types of helicopters, particularly the ability to detect in time to avoid a lethal gas concentration. He also discussed the toxic airflow in the cockpit. In addition, he stressed the relevance of proper donning of the NBC gear.

SESSION 3. Psycho-physiological aspects in rotary wing operations.

This Session consisted of papers addressing a number of questions related to the cognitive and personality factors involved in the helicopter operations and its aeromedical assessment.

Paper number #13, presented by Mrs. Fonne and Dr. Wagstaff reviewed under the title "Health, environment and safety (HES) in military aviation: Implications for the RNoAF new search and rescue (SAR) program", the approach of the RNoAF in developing a quality control system for military aviation in order to emphasize and improve occupational health and safety in military aviation operational environment. The investigation was divided into our main areas related to Ergonomics and Human/Machine interface, Software and automation, Cockpit Environment and Personal Flight Equipment. A number of specific requirements were stated for each area and a weighting and scoring designed. It is believe that this system will improve the crew's health and safety in an operational environment.

Capt. Katz and al. presented paper #14 on "Rotary-wing crew communication patterns across workload levels" where they dealt with the coordinated behaviors of the helicopters aircrew, mostly in relation to crew communication patterns and how those patterns are affected by high stress, high workload environment inherent to this milieu. They used the Coordination Index Rating of Crew Linguistic Events (CIRCLE) system to analyze paired verbalizations reflecting crew coordination basic qualities across flight phases requiring varying workload levels. Results showed the ability of CIRCLE to address specific fluctuations in communications patterns, suggesting the potential utility of the system towards analysis of other factors affecting crew communications.

In paper #15 Mr. Estrada and co-workers presented the study entitled "Assessment of simulated spatial disorientation scenarios in training US Army aviators" concerned with enhancement of awareness and training of Army Aviation Pilots, by using simulated Spatial Disorientation scenarios. Results showed that the majority of scenarios attracted a most favorable rating in their value to increase aviator's awareness of the circumstances in which SD is most prevalent in rotary-wing operations. It is concluded that this type of continuation training is valuable and could readily be utilized in existing flight simulators.

Dr. Raj and co-workers in paper #16 on "The tactile situation awareness system in rotary wing aircraft: Flight test results" presented the results of using the Tactile Situation Awareness System (TSAS) to improve Situational Awareness (SA) by presenting three dimensional orientation information to pilots and aircrew intuitively via somatic tactile sensory receptors. Pilots performed a series of forward flight maneuvers wearing a blackout visor to exclude any visual cues and a series of hover maintenance wearing semi-fogged spectacles to exclude external visual cues. Pilots reported adequate spatial orientation despite attempts to disorient them. Pilots hovering out of ground effect held position more accurately and confidently performed simulated shipboard take-off and landings without external visual cues. It was concluded that TSAS can provide significant SA improvement in rotary wing aircraft while reducing pilot workload and has great potential for the future.

In paper #17, Dr. Medialdea and Dr. Rios presented under the title of "Fear of flying in SPAF helicopter pilots" a review of the factors related to fear of flying in a population of 55 helicopter aircrew out of 446 with the diagnostic of "Fear of Flying" over a period of eight years. They analyzed the frequency of phobia to flight, its relation to aircraft accidents and flight motivation, as well as the presence of other psychiatric diseases. Therapeutic approach and management was discussed.

Paper #18 was presented by Capt. Katz under the title of "Assessment of aircrew stress" where his team analyzed the results of an extensive questionnaire distributed among the aircrew of an aeromedical evacuation unit. Items were related to causes of stress, coping skills, personal beliefs and stress symptoms. A symptom model was generated, illustrating the connection between harboring resentments and behavioral and emotional symptoms. The study demonstrated the utility of this questionnaire for assessing unit-specific stress factors and guiding interventions and an intervention programme has already been introduced with good results.

Commander Yauneridge and Mr. Kennedy presented paper #19 on "Safety of flight and anthropometry in United States Navy aircraft". They addressed the safety concerns to standardize methods to evaluate crew accommodation to the cockpit. Purposes of the paper were to predict equations that are used to determine a percentage of a target population that can be expected to be accommodated in a particular aircraft or aircraft pilot selection programme to define aircrew candidate selections for assignments based on achieving a suitable seat position. The cockpit evaluations were made in a variety of naval helicopters and aircrew accommodation data were collected in both crew stations with test subjects attired in full complement of summer flight gear. Analysis of the evaluation identified the personnel with specific physical dimensions that require a fit check.

In their paper #20 entitled "Lowback pain in helicopter pilots. Objective measurements by muscle tester" Capt. Vallejo and co-workers studied a group of helicopter pilots by measuring the activity generated by the lumbar muscles during real flight. Significant increased muscular activity was founded preferently in the right side related to flight activity. They concluded the validity of the method as a resource to evaluate the proper position of the pilot during flight control activities and his/her interface with the ergonomic characteristics of the seat.

M. C. A. Seynaeve presented paper #21 entitled "Back pains of helicopter pilots". He presented the results coming from a survey among helicopter pilots of the French Army Aviation made in 1996, with 560 responses (476 pilots and 84 flight engineers) in relation to presence of back pain related to crew position and flight time. In addition to that he compared this survey with a previous one made in 1976. The main findings were that there was a decrease of lumbar pain (16.5%), increase of cervical pain (7.2%) and increase cervical and lumbar pain (14.5%), the increase was possibly related with the use of night vision goggles.

SESSION 4. Human factors and life support equipment.

The paper presented by Mr Loeslein and his colleagues (#22) described the very poor performance of the US Navy liferaft and described a new programme to ameliorate the problem. This was followed by a second paper on liferaft performance from Dr Brooks from Canada on the overall performance of civilian and military liferaft worldwide (paper #23). He described the overall abysmal performance and made recommendations for improvement. This was followed by a paper entitled "Utilization of Medical Support Equipment on Board Army Rotary-Wing Aircraft" (paper #24) on the complicated and expensive procedures to approve medical/clinical equipment for airworthiness. On a clinic theme Professor Giesbriecht and his colleagues (paper #25) presented a very practical and simple re-warming device for rescuing patients in helicopter aeromedical evaluations. Mr Oudenhuizen presented a paper titled "Ergonomics of the Cockpit – Anthropometric Accommodation in the Apache Crew System" (Paper #26) and described the method used to select Dutch aviators both male and female for flight training in the Apache taking into consideration the large size of the Dutch population and that they are still growing in height.

Dr Caldwell (paper #27) and his co-workers then presented a paper on the comparison of the effects of amphetamine in pilot performance in the simulator and true flight. The conclusion was that the simulator is an excellent first step in the analysis of drugs, which are being possibly approved for flying. On a similar topic (paper #28), Dr LeDuc presented a study on the effects of Zolpiden and exercise on the performance of sleep deprived pilots. The conclusion was that Zolpiden was far superior to exercise. The next series of papers were basically related to human engineering and biodynamics. Dr Rood described the advanced UK design of helicopter pilot helmet and helmet mounted display technology (paper #29). Mr Rash and his colleges at the US Army Aeromedical Research Laboratory, Fort Rucker, described the schedule of tests and the human factors considered in the introduction of US Army aviators helmets (paper #30). Dr Barazanji continued with the same topic, and discussed the design of helmets for female aviators (paper #31). To complete this series of papers on head mounted devices, Dr McLean and colleagues described the development of night vision goggles in the US Army, and demonstrated a remarkable improvement in performance over the last 10 years (paper 32).

Papers 33 and 34 were related to hearing protection in the helicopter. Dr Wagstaff and Dr Woxen described the Royal Norwegian Air Force research on double hearing protection and speech intelligibility and that there was room for improvement, and Mr Mozo and colleagues described the improvement in hearing protection, but there were still problems related to the introduction of active noise reduction.

Paper 35 was presented by Grp Capt. Graham-Cumming on the "Effect of a moulded support for the treatment of backpain in fixed wing and helicopter pilots". He showed that there was considerable success with both groups of pilots, but it was more effective for the fixed wing pilots. The final paper in this series (paper #36) was presented by Dr Tipton from the University of Portsmouth on the requirement for an underwater breathing apparatus to assist helicopter pilots and passengers to escape from a ditched helicopter in cold water.

SESSION 5. Rotorcraft Accident and Crashworthiness

In paper #37, Ms B.R. Contarino and co-authors reviewed the "US naval and marine corps, and marine corps helicopter mishap trends: Over water mishaps (1985-1997)" and described the work made by the Naval Air Systems Command. The goal was to increase the level of safety and survivability for aircrew and passengers involved in mishaps. It was made by an analysis of airframe crashworthiness and victims survivability. This analysis pointed out emerging technologies, which could be used for airframe safety, occupant seating and restraint, post crash survivability and improving survival equipment.

Col. H.D. Marwinski, presented paper #38 on "Helicopter flight accidents in the German federal armed forces in the last 15 years". This study revealed a total accident rate, from January 1984 until today, of 0.22 per 10.000 hours. Most of these accidents were due to spatial disorientation and empty field of myopia. This remarkably good flight safety record was attributed to an excellent flight safety programme, high morale and a consolidated team approach to the flying programme enhanced by excellent CRM.

LTC J.S. Crowley in paper #40 on "Benefit of crashworthy design in attack helicopters: a comparison of accident fatality rates" presented the gain obtained, in term of survivability by crashworthy helicopter design. The methods used for improving crashworthiness were load absorbing structures or collapsible parts of the helicopter, crash resistant fuel system and energy absorbing seats. In the AH-64A Apache crashworthy helicopter design, the mortality rate and the head injuries rate, observed after a crash, were less than the rates observed in the same conditions with the AH-I Cobra.

Paper number 41, presented by B.J. MacEntire under the title "Aeromedical and design issues of the helicopter airbag restraint system" demonstrated that bodily contact with cockpit structure remains the leading cause of serious and fatal injury in survivable helicopter mishaps. As a countermeasure, the US Army is developing a cockpit airbag system for use in the UH-60 Black Hawk as a supplemental restraint system. Many design challenges remain, but various performance requirements, rationale, lessons learned and operational issues of the cockpit airbag system are presented and discussed in this paper.

In paper #42, Mr F.T. Brozoski and co-authors presented under the title "Mass and location criteria of head-supported devices using articulated total body simulations" their work concerning the biodynamic responses of the head during simulated helicopters crashes. With different experimental conditions they determined the risk of neck injury. They demonstrated that helmet mass and location is critical for good protection in crash conditions.

CPT R. Wildzunas and co-authors in paper #43 on "External position lighting effects on night vision goggle performance" described the consequences of the different lights in the cockpit, mounted to the aircraft or external to the aircraft on the perception quality of the environment with night vision goggles. They demonstrated the effects of the left red light mounted on the aircraft fuselage on the degradation of the image quality. They suggested new civilian regulations regarding red lighting.

In summary, this was a most successful symposium and covered a very wide range of aeromedical and human factor topics, for instance from night vision goggle performance to backache in helicopter pilots from training in underwater escape to spatial disorientation, from liferaft performance to crashworthiness of the cockpit.

In each area, the message is quite clear – the human is the weak link in all aspects of helicopters operations, and generally the engineers and designers have not considered this. As an afterthought when the helicopter is designed, only then do the look at shoehorning a human being into the cockpit. This philosophy must change and this conference proceedings and symposium have hopefully drawn attention to these deficiencies.

L'IMPORTANCE DU FACTEUR HUMAIN DANS LES OPERATIONS AEROMOBILES DE LONGUE DUREE

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Introduction

C'est un grand honneur pour moi de pouvoir m'exprimer ce matin devant vous d'un sujet qui me tient particulièrement à cœur.
Tout au long de ma carrière, j'ai eu la chance de pouvoir commander, en unité opérationnelle ou en école, des personnels dont j'ai pu apprécier les qualités.
C'est donc avec beaucoup de plaisir que, comme chairman, actuellement commandant de l'aviation légère de l'armée de terre française, je vais tirer quelques conclusions des expériences récentes de l'ALAT dans les opérations aéromobiles de longue durée et partager avec vous quelques réflexions sur l'importance du facteur humain au cours de ces opérations.

A cet égard, je citerai deux exemples particuliers : les opérations contre l'Irak en 90-91, où nos équipages ont effectué près de 16500 heures de vol sur 126 hélicoptères sans que nous ayons eu à déplorer des cas de stress de combat ou de tirs fratricides au cours de l'engagement armé. Il s'agit du type même d'opérations aéromobiles de longue durée, où les équipages demeurent de longs mois dans un environnement inhospitalier.

Pour illustrer le deuxième type d'opérations que je qualifie de longue durée, je citerai l'opération Antilope, au cours de laquelle 6 équipages ont parcouru plus de 9500 miles nautiques en 200 heures de vol, à partir de N'Djaména et Bangui via Yaoundé et Libreville, pour participer à l'extraction de 79 ressortissants en danger, lors de la guerre civile qui les menaçait au Congo en 1997.
Ce deuxième type d'opérations ne s'étend pas dans la durée, mais est caractérisé par une forte densité d'heures de vol.

Dans ces deux types d'opérations, la qualité humaine des équipages a constitué un élément primordial du succès.

En effet, au-delà de tout le côté technique, c'est sur l'homme que, en dernier ressort, repose la clef du succès.
Aussi, le facteur humain apparaît comme un défi majeur à relever par le commandement.

I. EN DERNIER RESSORT, C'EST SUR L'HOMME QUE REPOSE LA CLEF DU SUCCES

11. L'homme maillon faible d'un système complexe

La complexité des savoir-faire mis en œuvre dans les actions aéromobiles confère à l'homme une place prépondérante.

111. Gérer l'intensité

La vitesse d'exécution des missions aéromobiles, les distances parcourues du fait de l'affranchissement du terrain, accroissent l'isolement du combattant aéromobile.

C'est dans cette position fragilisante que les équipages aéromobiles doivent gérer des systèmes d'armes de plus en plus complexes : il leur faut prendre en compte les contraintes tactiques qui découlent de la situation ennemie et les impératifs tant en matière de coordination qu'en ce qui concerne la gestion de leurs appareils.

Dans ce contexte, les combattants aéromobiles effectuent les choix qui déterminent la sécurité de la mission, voire la survie des équipages.

112. Résister dans la durée

Par l'entraînement, il est relativement aisé de placer les équipages dans des situations qui les obligent à gérer l'intensité, et de les rendre aptes à faire face.

Néanmoins, l'entraînement ne reproduit que rarement ou imparfaitement toutes les pressions qui s'exercent sur les hommes du fait de la durée des opérations.
La récupération est parfois mal aisée, et la difficulté accrue par la fatigue physique et le stress.
A cet égard, il faut noter l'importance du contexte dans lequel se déroulent les opérations : la chaleur et le froid représentent des contraintes importantes sur les équipages, l'hostilité du milieu peut aggraver le stress de façon notable.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

113. S'adapter à l'imprévu

La réalisation de la mission requiert donc une capacité d'adaptation importante du combattant aéromobile.

Certes, la préparation de la mission permet de déterminer les conduites à tenir dans la majorité des cas, mais en dernier ressort, c'est au combattant d'analyser la situation et de prendre les mesures ad hoc.
De plus, certains enchaînements de problèmes (météorologiques, mécaniques ou dus au combat) nécessitent des prises de décision rapides.

On le voit, le combattant aéromobile, pris dans un contexte souvent déstabilisant, éloigné de ses repères traditionnels (famille, pays..), doit gérer un système d'armes performant et un flux d'informations important : il devient le maillon faible d'un système complexe.

12. Les qualités fondamentales requises chez le personnel navigant

Il convient par conséquent de déterminer les qualités fondamentales requises chez le personnel navigant, qui lui permettront de faire face efficacement aux problèmes auxquels il est confronté lors des opérations aéromobiles de longue durée.

121. Une capacité d'analyse et de synthèse

En tout premier lieu, les personnels navigants doivent posséder une bonne capacité d'analyse et de synthèse : il s'agit de déterminer rapidement le moment où la mission subit de telles contraintes qu'elle sort du cadre exact de la planification, et de trouver une réponse adaptée à la situation, de façon à remplir la mission.

Sans aller jusqu'à ce cas extrême, il s'agit d'analyser et de synthétiser dans les moments importants de la manœuvre un flux d'informations important, afin d'agir au bon endroit, de parer la menace la plus pressante, de rendre compte à l'échelon supérieur voire de donner des ordres à un ou plusieurs subordonnés.

122. Une capacité d'endurance

La seconde capacité exigée chez le personnel navigant est la capacité d'endurance. Physiquement entraîné, il doit être suffisamment rustique pour tenir dans la durée.

Il doit par conséquent pouvoir résister aux climats rudes dans des conditions de confort minimum. Souvenons-nous à cet égard des trois mois passés dans le désert par les équipages de l'opération "Desert Storm" avant l'engagement contre l'Irak.

A la différence des équipages d'avions confortablement installés sur des bases aériennes.

A la différence également des équipages embarqués sur porte-avions et/ou porte-hélicoptères et qui vivent dans des conditions difficiles de bruit et de mer.

123. Une force morale et mentale

Il faut des personnels psychologiquement forts ; par essence, le combattant aéromobile agit souvent de façon isolée, loin des lignes amies, souvent même sans voir son chef direct. Il doit par conséquent savoir surpasser un inévitable stress de combat.

Il dispose d'une puissance de feu considérable, qui s'accroît à mesure que les appareils se modernisent, mais dans le même temps, il doit gérer les problèmes de dégâts collatéraux et éviter toute méprise qui l'entraînerait à délivrer des feux fratricides.

Ces dernières années ont vu s'accroître le nombre d'équipements qui allègent le travail des équipages d'hélicoptère dans la phase des combats : aides à la navigation, aide à la vision nocturne, détecteurs de départ missile.....
Néanmoins, demeurent toujours le stress, la fatigue qui font de l'homme le maillon faible du système d'arme ; c'est sur l'homme que, in fine, repose la clef du succès, c'est pourquoi une attention toute particulière doit lui être consacrée.

II. LE FACTEUR HUMAIN, UN DEFI A RELEVER PAR LE COMMANDEMENT

21. Assurer une formation complète

Il faut donc au commandement agir dans le domaine de la formation, de façon à engager dans les actions de combat des équipages parfaitement aptes à tenir, à gérer et décider.

211. Sélection

A cet effet il importe de pouvoir réaliser une sélection adaptée aux besoins spécifiques que nous avons évoqués
L'ALAT a choisi d'opérer cette sélection en prenant en compte les résultats de trois séries de tests.

Les candidats personnels navigants, après avoir passé les tests standards de l'armée de terre sont convoqués dans notre antenne de sélection ou ils font l'objet d'une batterie de tests : dissociation de l'attention, réflexes et coordination sont évalués sur une plate-forme.
Des tests de personnalité permettent ensuite d'obtenir un profil médico-technique : la stabilité, la

sociabilité, mais aussi la logique, la représentation dans l'espace et la capacité de gestion sont jugés.

Un entretien permet alors d'apprécier la personnalité du candidat, ses motivations profondes et sa capacité d'adaptation.

Ainsi, des candidats qui ont été filtrés par les centres de sélection de l'air de terre, seulement 10% sont retenus.
Il s'agit bien entendu d'une sélection tout à fait particulière dans l'armée de terre, qui permet d'obtenir un recrutement moyen situé entre BAC+1 et BAC+2 pour les sous-officiers. Equivalent niveau BAC à préciser pour les étrangers.

212. Formation morale et psychologique, capacité physique

Ayant sélectionné des personnels en fonction de leurs capacités psychotechniques et de leur personnalité, il faut alors avoir une action de formation.

C'est l'objet des écoles de formation initiale, écoles d'officiers ou de sous-officiers : les qualités de combattant sont alors développées ainsi que celles nécessaires à l'exercice de l'autorité.

L'entraînement sportif, la participation à des stages commando, à des raids ou des exercices de survie permet d'endurcir les corps et de former les caractères, mais cet entraînement doit par la suite être complété ou au moins continué. La conservation d'une mémoire physique et psychologique est nécessaire.

C'est l'objet d'actions spécifiques de formation au sein des unités, à l'image du stage survie en montagne dans notre Centre National d'Aguerrissement en Montagne, auxquelles participent les escadrilles et qui est destiné à les entraîner aux procédures CSAR (Combat Search and Rescue) et à la survie en territoire hostile.

213. Formation technique et tactique

Néanmoins, la part la plus importante de l'instruction doit résider dans la formation technique et tactique.

La dissociation de l'attention est une qualité fondamentale qui permet aux membres d'équipage de gérer la mission dans son ensemble : suivi tactique, navigation, contrôle instrumental, procédure radio...
Il faut donc accroître cette capacité chez les personnels navigants en les entraînant, par exemple, à gérer leurs vols avec des systèmes fonctionnant en mode dégradé. (Simulateurs: LMT, SHERPA)

La formation des équipages est assurée à l'école d'application de l'aviation légère de l'armée de terre. la formation initiale se déroule sur la base école de DAX, la formation spécialisée sur la base école du LUC EN PROVENCE. Cette formation puis l'entraînement tactique doivent pouvoir préparer les équipages aux conditions difficiles : météo, élongations, guerre électronique...

Issus d'une sélection rigoureuse, formés d'abord comme des combattants, puis comme des spécialistes, maîtrisant parfaitement leur domaine technique et instruits à combattre dans les conditions les plus difficiles, les personnels navigants sont alors aptes à être projetés en cours d'opération aéromobiles de longue durée.

22. Assurer une gestion suivie du facteur humain pendant toute l'opération

L'action du commandement en matière de facteur humain ne doit pas se limiter à sa prise en compte dans les actions de formation. Il s'agit en effet de le prendre en considération pendant toute la durée de l'opération.

221. Constitution des unités déployées

Dans la constitution des unités engagées dans les opérations aéromobiles, le commandement a traditionnellement le choix entre l'engagement d'unités organiques et la constitution d'unités de marche, à partir de réservoirs que représentent les différents régiments aéromobiles.
La première solution bénéficie de l'avantage que constitue l'entraînement commun, et l'excellente connaissance qu'a le chef de ses subordonnés. Elle bénéficie des solidarités nées au cours des entraînements et permet une excellente appréhension du facteur humain. Exemples: l'exercice PAU-DAKAR du 5°RHC, le retour du KOWEIT via l'EGYPTE vers la FRANCE (col de Crémiers)
La seconde solution offre l'avantage de pouvoir sélectionner une élite pour les opérations délicates et permet de constituer sur le papier une unité au niveau technique exceptionnel et rompue aux différents types de combat.
La prise en compte du facteur humain comme facteur constitutif primordial dans les opérations aéromobiles milite donc pour le choix de la première solution.

222. Adaptation du soutien

Pendant la durée de l'opération, et c'est d'autant plus important que l'opération est longue, il importe de soutenir le moral du combattant aéromobile, en lui assurant une logistique adaptée dans la mesure des possibilités locales (hébergement, alimentation, eau...)

Les mouvements séditieux qui avaient affecté les troupes françaises en 1917 avaient disparus rapidement dès lors que le commandement avait pris des mesures pratiques destinées à soutenir son moral : permissions, amélioration des conditions de vie...

C'est une excellente leçon qui montre que le moral, et partant la capacité du combattant aéromobile, est lié à l'effort du commandement pour assurer un soutien cohérent dans des domaines sensibles comme l'acheminement du courrier ou l'aménagement des permissions pendant les séjours de longue durée. Il conviendra également une gestion harmonieuse des temps de repos et d'activité en privilégiant la notion d'unités constituées. Exemple : équipages par relève. Il n'est pas toujours utiles que tout le monde soit activé en même temps, si cela n'est pas nécessaire. Cela implique par conséquent une meilleure gestion du sommeil, mais qui pourra dans certaines circonstances exceptionnelles, (début du conflit par exemple) autoriser la mise en place de substances pharmacologiques spécifiques (médicaments ou pilules anti-sommeil comme le MODAFINIL).

223. Analyse a posteriori

Le suivi du facteur humain ne s'arrête pas à la fin de l'opération. Il est essentiel d'assurer un suivi a posteriori des équipages qui ont participé aux opérations aéromobiles.

D'une part, il est quelquefois nécessaire d'aider certains pilotes à surmonter le traumatisme que constitue la rencontre avec la mort, et d'autre part le débriefing "facteurs humains" après l'action constitue un excellent moyen de préparer l'avenir, en réfléchissant avec les acteurs de l'action, aux mesures pratiques à mettre en œuvre pour préserver le potentiel humain lors de l'engagement des équipages.
Le service de santé des armées à mis en place ces dernières années (guerre du Golfe, ex-Yougoslavie...) des spécialistes psychiatres chargés du soutien psychologique des combattants aéromobiles. Ceci aussi bien dans le cadre d'une action préventive que curative. La mort et son vécu immédiat engendrent des effets ou dégâts psychologiques aussi important que les armes.

23. Exercer une action spécifique

L'action du commandement dans la prise en compte du facteur humain ne se limite pas à la formation et aux périodes d'opérations. Il faut une action spécifique qui puisse, par exemple, s'exercer dans trois directions différentes.

231. Effort sur la capacité psychologique des unités

Depuis quelques années, notre armée de terre, par le biais de son centre des relations humaines, quantifie la CAPSU, capacité psychologique des unités.

Les résultats montrent que cette CAPSU est d'autant meilleure que l'entraînement s'avère difficile. Les difficultés de l'entraînement améliore la confiance en son chef et augmente la cohésion.
Il y a donc lieu de programmer des exercices sur des durées suffisantes pour que les unités s'entraînent ensemble à assurer leur "vie en campagne".
L'évaluation de la CAPSU met également en évidence la place de l'esprit de corps : plongeant ses racines dans son passé, l'esprit de corps est le ciment d'une cohésion nécessaire des personnels autour de leur chef qui leur permet de se dépasser pendant les moments difficiles. Cet esprit est entretenu en temps de paix par les relations conviviales qui existent au sein des unités et les activités en commun qui réunissent les personnels et permettent à chacun "d'obéir d'amitié".

232. Effort sur la communication

C'est en matière de communication que des efforts importants ont été entrepris par l'ALAT depuis quelques années.

Il s'agit d'avancer notablement dans le cadre des facteurs humains, dispensés à l'EA.ALAT base école de DAX pendant la formation initiale des pilotes et de la mise en place d'un cours CRM (Cockpit Ressource Management) appliqué aux équipages Puma et Cougar de l'ALAT, et d'améliorer encore la sécurité des vols par ce biais.

Le MC GRAU de l'IMASSA de Brétigny, vous présentera au cours de ce congrès, cette importante action qui débouche déjà aujourd'hui sur la mise en place de cours spécifiques, CRM PUMA/COUGAR dans notre école d'application du Luc en Provence et au sein d'autres unités.

L'exemple assez récent d'un de nos Puma crashé, au retour d'une évacuation sanitaire, sur le territoire de l'ex-Yougoslavie par des conditions météorologiques marginales, nous prouve l'importance de la communication au sein des équipages, spécialement en opération, où l'accomplissement de la mission pousse les équipages à accepter une prise de risque accentuée. La complexité sans cesse croissante du vol hélicoptère pour notre part a imposé le concept d'équipages toujours les mêmes notamment lors du dernier conflit de la guerre du Golfe. Ceci dans le but de renforcer la confiance autour de chaque équipage.

Une coopération entre médecins et opérationnels permet donc d'améliorer cette communication, en particulier dans le domaine des procédures. Ceci m'amène à évoquer maintenant le stress de combat.

233. Lutte contre le stress de combat

La troisième voie à exploiter par le commandement est la lutte contre le stress de combat. Son 'étude montre que le comportement face aux facteurs stressants, découlant de la situation, de l'environnement physique et de l'environnement psychosociologique, évolue en fonction des capacités intellectuelles et physiques et de la personnalité : l'expérience et la motivation jouant un rôle fondamental.

De plus, la perception des facteurs stressants par les individus peut avoir une influence au moins aussi importante que leur réalité objective. Il faut donc aguerrir les combattants aéromobiles en les habituant aux dangers du combat, aux difficultés du vol et en les plaçant dans des contextes qui leur sont peu familiers.

A cet égard, l'embarquement assez fréquent, (évocation de l'exercice de combat annuel DAMTAM et de ses contraintes : survol maritime avec le risque d'une panne mécanique, provoquant un crash en mer) de nos appareils sur les bateaux de la Marine nationale permet aux équipages de s'habituer à un mode de vie particulier par son confinement et son rythme de travail.

En matière de vol, une des façons de replacer les équipages dans des conditions difficiles demeure le vol en montagne, qui constitue pour beaucoup une excellente école d'humilité. Il faut aguerrir les équipages si possible en milieu inhospitalier : l'ALAT pratique ainsi régulièrement le survol en milieu maritime et entraîne un certain nombre d'équipages au vol dans les conditions désertiques à l'occasion de séjours en Afrique. Exemple : Appontage raté (de nuit) au large de BEYROUTH équipage fatigué par la vie embarquée et aggravé par une communication insuffisante.

Dans le domaine du combat, les possibilités ouvertes par les moyens modernes de simulation sont à même de procurer des moyens réalistes et efficaces pour placer les équipages dans des situations de stress et d'augmenter ainsi leur accoutumance.
Elle complétera l'expérience du vol de combat, qui demeure toutefois irremplaçable.
Toutefois, il faudra toujours se forcer de limiter (chiffre difficile à apprécier) le pourcentage de simulation dans le cursus de formation initiale puis spécialisée (apport des systèmes d'armes sophistiqués entre autres).
L'argumentation économique avec la réduction des heures de vol, ne devra en aucun cas prévaloir sur l'apport représenté par l'expérience acquise en vol.

Ce sera le prix à payer pour une meilleure sécurité des vols.

Conclusion

En prenant en compte le facteur humain dès la préparation de l'opération en portant une attention particulière par la suite, le commandement possède le moyen de lutter contre l'usure qui affecte les équipages lors des opérations aéromobiles de longue durée. Il s'agit donc de leur permettre d'être en possession de tous leurs moyens pour s'adapter aux situations auxquelles il leur faut faire face et gérer des systèmes d'armes complexes.

Le facteur humain est donc un élément essentiel à prendre en compte par l'opérationnel, mais aussi par l'industriel dans la conception des matériels aéronautiques : ergonomie, probabilité de survie au crash ou aux impacts participent de façon notable à la capacité des équipages à réaliser leur mission.

J'insisterai également sur deux autres points :
- L'abandon de la situation traditionnelle en côte à côte au profit de celle en tandem avec l'arrivée du TIGRE.

Pour les équipages de l'ALAT, cela représentera une véritable révolution au regard de l'habitude de travailler par gestes en complément de la communication verbale.
Par le TIGRE, la séparation de l'équipage ne manquera pas de provoquer des difficultés en matière de communication.
- Et la juste part faite aux entraînements dans une ambiance opérationnelle la plus proche de la réalité avec maintien d'un niveau de sécurité optimum.

En effet, rien ne devrait justifier une prise de risque disproportionnée.

CONTROLLING THE HAZARD OF SPATIAL DISORIENTATION IN ROTARY-WING OPERATIONS BY ENHANCED TRAINING

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1. SUMMARY

Spatial Disorientation (SD) remains an important source of attrition in military flying. Several recent symposia and technical meetings have recommended various initiatives to control this hazard such as education, training, research and technological improvements. This paper gives details of the various training initiatives that have been established through the Technical Working Group (TWG) of the Triservice Aeromedical Research Panel, and the international forum of Working Party 61 of the Air Standardization Coordinating Committee (ASCC). Nations and individual services were asked to contribute to a panel to consider how the hazard of SD could best be controlled by means of training enhancements. All aspects of existing and potential training were reviewed: classroom instruction; ground based demonstrations and training in both dedicated SD demonstrators and flight simulators; in flight demonstration and training; SD training for special forms of flight; and training the SD trainers. It was clear from this review that many improvements were required, and that most could readily be adopted. It must be remembered that training is not necessarily the only, or even the preferred solution to the various problems associated with SD. Nevertheless, where training can help, it must be regarded as the most readily applied control. The most specific enhancement identified was to make SD training more "experienced-based." This essentially implies more simulator and in-flight demonstrations, and better SD preventive and management procedures.

2. INTRODUCTION

2.1. Spatial disorientation (SD) remains an important source of attrition in military flying. Recent reports have estimated that SD contributes to between 5 and 42 percent of aircraft mishaps (Table. 1). On average, these accidents annually cost the U.S. Department of Defense approximately $300 million, and 12 lives. Several recent symposia and technical meetings [1,2,3] have recommended various initiatives to control this hazard, such as education, training, research and technological improvements.

2.2. Under the auspices of the U.S. Triservice Aeromedical Research Panel (TARP), a Technical Working Group (TWG) for Spatial Orientation and Situational Awareness coordinates interaction and information exchange between the services. This group realizes that research and technological initiatives that deal with SD will require a great detail of effort and money to implement. However, training enhancements, where appropriate, can probably be more readily achieved and so should be addressed without delay. Therefore, in early 1997 a subgroup was established to review and make recommendations on SD training. It was agreed that the charter of the subgroup should be ".... to review current procedures for training aviators and associated aviation personnel concerning SD, and to make recommendations for improvement...." Two meetings of this group have been held with representatives attending from training, operational, and research organizations.

2.3. Subsequent to the TWG meetings, Working Party 61 (Aerospace Medicine, Life Support and Aircrew Systems) of the Air Standardization Coordinating Committee (ASCC) formed a dedicated Project Group to consider standardization aspects of SD. One Air Standard, No. 61/117/1, Aviation Medicine/Physiological Training of Aircrew in SD [13] has been produced and has been ratified by the ASCC member nations (U.S.A., U.K., Canada, Australia, and New Zealand). The work commenced by the TWG has thus now been taken into the international arena and will be of interest and value to NATO and PfP nations.

2.4. This paper comprises a summary review of the various aspects of SD training, the conclusions of the TWG subgroup and recommendations for future action. Novel innovations are described in greater detail.

Table 1. Recent accident statistics

Authors	Years	SD accidents (% of total)
Lyons et al (USAF) [4]	1990-1991	14 %
Knapp & Johnson (USAF: F16) [5]	1975-1993	7.5 %
Bellenkes et al (USN) [6]	1980-1989	5 %
Mason (USMC : rotary-wing) [7]	1990-1996	42 %
Braithwaite et al (US Army RW) [8]	1987-1995	30 %
Cheung et al (Canadian Forces) [9]	1982-1992	22.5 %
Vyrnwy-Jones & Turner (Royal Navy) [10]	1972-1984	6 %
Braithwaite (British Army RW) [11]	1983-1993	17 %
Stott (Royal Air Force) [12]	1973-1991	12 %

3. CLASSROOM INSTRUCTION

Classroom instruction has been the mainstay of SD awareness for many years but with the general acceptance of the Systems Approach to Training, a critical review of the course content is now especially important.

3.1. Review

The content of SD classes during initial physiological training is considered satisfactory and generally follows the existing NATO STANAG on Aeromedical Training [14] and the recent specific AIR STANDARD [13]. The quality of classroom teaching appears to have improved in the light of recent mishaps, and consequently, there has been an increase in case-based teaching throughout the services which is encouraging and should be promoted further. The U.S. Air Force have commenced distributing standardized lesson plans on CD ROM which has proved popular. The timing of initial classes could, however, be refined (this is addressed in the following paragraph). The standard of transition and refresher training is extremely variable, and depends largely on the enthusiasm of the instructor. Attendance on refresher courses can be enhanced by holding a mandatory examination on the subject.

3.2 Recommendations

It would be advantageous for each service to continually assess its standard of classroom training in SD, and especially attempt to improve and standardize transition and refresher courses. Training video films are also extremely valuable, and if services do not have

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their own publication, the U.K. film, “Puzzling Perceptions” [15] is a first class production with international appeal and triservice relevance.

4. TIMING OF INITIAL TRAINING

The timing of aeromedical instruction within a flight course is often constrained by other curricular activities. Nevertheless, as it is a most important part of the student pilot's training, its scheduling should be optimized.

4.1 Review

The U.S. services agree that initial training in SD is probably too far in advance of flight training. There is a danger that flight students forget important material concerning SD before they get the chance to experience SD in flight. Training of any nature is probably more effective if distributed over several sessions, but the precise nature of any “erosion of skills” requires careful evaluation

4.2 Recommendations

Because of the difficulty in instituting syllabus changes in military flight training, it is recommended that the initial “block” of SD training is retained at its present stage, but a second, short refresher block is inserted after students have completed some elementary flight training and before they commence instrument flight training. An assessment of the retention of aeromedical knowledge in SD would be valuable, since much of what students learn about SD is not formally tested, and therefore may not receive the attention it deserves.

5. SD AS PART OF CREW COORDINATION TRAINING

Crew coordination training (CCT) is also know as aircrew coordination training and crew resource management. Poor crew coordination has been cited as a factor leading to an increased risk of SD in many aircraft accidents (Fig. 1.) [8], and furthermore, good crew coordination has been considered to have prevented many SD mishaps (Fig. 2.) [16].

5.1 Review

SD appears to be mentioned in CCT training syllabi but there is no standardized syllabus. To enhance aircrew awareness, the hazard of SD should be explicitly included not only as part of CCT, but also during the mission risk analysis when planning specific missions.

5.2. Recommendations

Each service should examine the types of flight where the risk of SD is greatest, list them, and provide the information to CC trainers and mission planners for inclusion in these process. Some examples are discussed in the section on SD training for special forms of flight below.

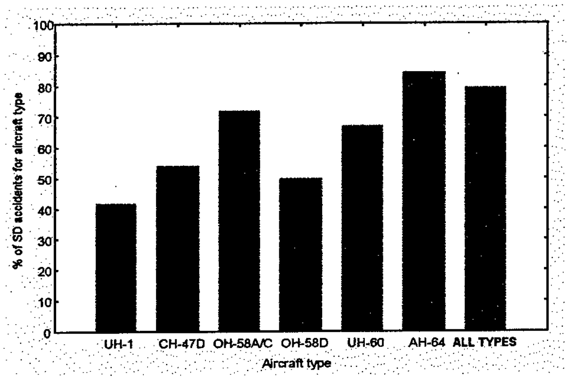

Fig. 1. Percentage of SD accidents in which poor crew coordination was implicated.

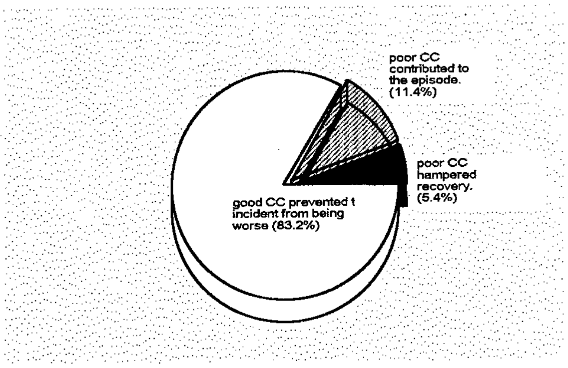

Fig. 2. Percentage of SD episodes in which crew coordination (CC) played a part [16].

6. GROUND-BASED DEMONSTRATIONS OF SD.

The Barany chair is probably an adequate introductory tool, and is still used by most services to demonstrate some of the limitations of the orientation senses and some basic vestibular illusions. However, as there are now sophisticated electro-mechanical demonstrators available and the technology of flight simulators has improved, enhancements to this vivid means of instruction is possible.

6.1. Review

The Barany chair should be used to demonstrate the perceptual threshold of rotation sensations, the somatogyral illusion, the Coriolis effect, and the vestibulo-ocular reflex. If used as the only means of demonstration, as many students as possible should experience these phenomena. The Gyro series and the Advanced Spatial Disorientation Demonstrator (ASDD) are sophisticated ground-based demonstration devices. The former are used widely among NATO forces, whilst only two of the latter are currently available within NATO and thus the availability of training is limited. The U.S. Navy uses the unique Multi Station Disorientation Device for all initial and some refresher students, and is building three new research devices, some of which may provide useful experiences for research volunteers. The U.S. Marine Corp is developing Simulator-Physiological Integration of Flight Training (SIMPHYS). This is an important means for introducing physiological events into flight simulation scenarios, and their experience with this method should be monitored.

6.2 Recommendations.

The following recommendations are primarily concerned with enhancing ground-based demonstration and training in simulator devices. In all cases it is imperative that the sensations induced by the simulator are isomorphic (i.e., of the same form or equivalent to) the sensations felt during the real flight profile being simulated, and that they are also isomorphic to the coordinated "subconscious" reactions elicited from various sensory-motor systems during real flight. Furthermore, the training applications of these devices requires careful consideration, not only in terms of who is exposed, but also in the nature of the demonstrations. They are far from being a universal panacea for SD demonstration and training. Aeromedical research laboratories are in an excellent position to guide the choice of training tools and suggest ways to implement them to achieve training goals.

a. Ground-based demonstrations should not only be part of physiology training but also flight simulation training.

b. Dedicated SD demonstration and training devices. The procurement, and use of motion-based and centrifuge-based devices (e.g. the ASDD), even in limited quantities, should be examined.

c. Flight training simulators. NATO services should examine the benefits of further incorporation of SD training into present and future flight training simulators. Both motion and fixed-base simulators should be considered for procedural training and for inter-related combat mission training. All services should especially evaluate the usefulness of flight training simulators to demonstrate SD situations, and safely train students in preventive and recovery procedures. Specific scenarios derived from accident sequences would be valuable for the student to obtain direct experience in preventing and overcoming SD in a realistic setting. An example is as follows:

(1) Student flies the scenario and gets disoriented.

(2) Instructor debriefs student, explaining that this was an SD situation.

(3) Instructor then instructs, "how to prevent SD."

(4) Instructor then instructs, " how to overcome SD."

The U.S. Army has recently been successful in developing this methodology. The results of an initial assessment are comprehensively presented in paper 15 (Estrada et. al) of these Conference Proceedings.

d. Demonstrator operators. All SD demonstration and training devices should be operated by an adequate number of staff who have been properly trained in their function.

e. There should be closer coordination between research and training personnel to optimize the use of expensive facilities.

7. FLIGHT-BASED DEMONSTRATION OF SD.

This section is concerned **only** with **demonstration** of the limitations of the orientation senses in flight.

7.1 Review

The U.S. Air Force used to conduct an in flight demonstration but the programme was discontinued almost 20 years ago. As this form of training is not widely practiced, the experiences of the British Army and latterly, the U.S. Army is described below. Demonstrations within the actual flight environment are extremely valuable as arguably, the most meaningful way to train aircrew to recognize and overcome SD is to conduct SD training in-flight.

7.2. The British Army Spatial Disorientation Demonstration Sortie.

7.2.1.

In order to reinforce instruction in SD within the environment in which they operate, British Army Air Corps helicopter pilots also receive an airborne demonstration of the limitations of their orientation senses prior to rotary-wing instrument flight training. The sortie is described in full in a previous publication [17] and is briefly described below. The sortie is flown by a pilot-physician (Flight Surgeon) in the Gazelle AH1 helicopter, and three students can be flown on each sortie. During a short pre-flight briefing the overwhelming contribution of vision to orientation is stressed, together with the fact that SD is primarily a problem associated with poor external visual conditions, thus emphasizing why the students will be deprived of their vision during the exercises. In turn, the students close their eyes and give a running commentary of their perception of orientation with particular reference to altitude, heading and airspeed. The specific maneuvers have been chosen on the basis that they are simple to perform, are easily repeatable, and have operational relevance to the most commonly experienced types and degrees of SD. The other students are asked to observe but not comment until after the maneuver. Each student experiences at least one exercise in each of the forward flight and hover groups.

7.2.2. Exercise 1.

Straight and level flight is established at 100 knots. After 10 seconds a gently increasing (supra-threshold) roll to 30° angle of bank is commenced while maintaining airspeed and altitude. This is stabilized and, on completion of a 360° turn, the aircraft is rolled wings level again at a supra-threshold rate. The onset of the roll is normally detected, but as the semicircular canal response decays, a false sensation of a return to straight and level flight is perceived. As the roll-out to level flight is made, a sensation of turning in the opposite direction is perceived. The student is told to open his eyes once he considers that he is once again straight and level. The observing students are asked to tell the subject what actually happened and all are asked for their comments. The fight surgeon then reminds the students of the physiology of semicircular canal performance.

7.2.3. Exercise 2.

Straight and level flight is established at 100 knots and the aircraft is flown with no alteration of height, heading, or airspeed. Because of small aircraft movements from turbulence and the aerodynamic response of the helicopter which stimulate the kinaestheic and/or the vestibular apparatus above threshold, all students perceive climb, descents, or turns in unpredictable and varying amounts. The erroneous sensations produced by brief stimulation of the kinaestheic receptors and vestibular apparatus is discussed.

7.2.4. Exercise 3

Straight and level flight is established at 100 knots into wind. The helicopter is slowed within 30-40 seconds to a free air hover with no change of heading or height. Both the deceleration and the nose-up pitch associated with the attitude change at the final stages of slowing the aircraft, usually convinces the student that a cyclic climb is taking place. In addition, a turn is often falsely perceived when balance variations are made to keep straight.

7.2.5. Exercise 4

This maneuver is best commenced at about 500 ft above ground level. Straight and level flight is established at 100 knots, and then a descending turn is commenced as gently as possible. Within 30 seconds in the Gazelle, it is possible to lose 500 ft in height and turn through 180°. The student, remembering the second demonstration, usually states that he is straight and level. This demonstration forcibly and convincingly demonstrates a Type 1 orientation error, due to the proximity of the ground.

7.2.6. Hover.

The helicopter has a unique ability to accelerate about, as well as along orthogonal axes, thus the final series of demonstrations starts from a 5 or 6 foot hover. In turn, the three students are exposed to a variety of linear and rotational movements whilst maintaining hover height. The pilot keeps prompting the subject for a running commentary (to occupy channels of attention) and so exacerbate the onset of SD. Most aircrew are able to maintain their orientation for 10 to 15 seconds before losing it. Within these exercises it is possible to "hide" various manoeuvres so that when the student opens his or her eyes, a dramatic end point is evident:

a. climbing backwards at 10-15 knots.

b. landing without the student realizing it.

c. a gentle transition to forward flight.

These exercises have a most educational effect upon the observing students and are discussed in the context of snow, sand, and night hover and transition to the hover phases of flight.

7.2.7.
Analysis of helicopter accidents demonstrates that this training is operationally effective by contributing towards the reduction of SD related mishaps. It is cost-effective and the addition of this type of in-flight demonstration to the aeromedical training syllabus is regarded as being of great value to British Army helicopter aircrew. Similar instruction has now been adopted by the U.S. Army for their ab initio aircrew.

7.3 Recommendation.
An in-flight SD demonstration should be considered by all services. The feasibility of incorporating it into both initial and refresher flight training should be explored. The sortie may be readily adapted from the procedures followed by the U.K. and the U.S. Army.

8. IN FLIGHT SD TRAINING.

Whereas the previous section dealt with demonstration, this section is concerned with procedural training to overcome or manage SD in flight.

8.1. Review.
In general, there is limited training among services to avoid and overcome SD; rather the emphasis is placed upon experiencing SD and becoming convinced that one's senses are fooled. Different services have different mission needs. Current procedures are generally limited to the recovery from inadvertent entry to instrument meteorological conditions (IMC), and recovery from unusual attitudes, but are not always a required item on flight evaluations. Flight instruction manuals are aircraft-specific and cover unusual attitude recovery, but do not necessarily teach the pilot how to recognize SD. In conclusion, although this aspect of training may be appropriate, it is probably inadequate to properly train pilots.

8.2. Recommendations.
These recommendations address recovery from inadvertent entry to IMC and unusual attitudes. Other forms of flight associated with an increased risk of SD are addressed in the following section.

a. Specific training objectives on the training procedures to overcome or manage SD must be established.

b. More formal SD scenarios are required to enhance training, particularly to place more emphasis on Type II SD training. A suggestion is to routinely allow the student to enter an unusual attitude and then recover from it, in addition to the more traditional method in which the instructor places the student into an unusual attitude.

9. SD TRAINING FOR SPECIAL FORMS OF FLIGHT.

SD is a particular hazard for "special" forms of flight. Various aspects and recommendations are addressed under individual topics, and recommendations made. Services are encouraged to review their own special flight problems and implement appropriate controls. In particular, the use of simulators to safely train SD avoidance and recovery procedures should be examined.

9.1. Flight with night vision devices (NVDs).
When appropriate to the mission, all services conduct NVD training in the latter stages of initial flight training. In the U.S. Army, during the period, FY 1990 through 1995, the class A through C SD accident rate for flight using NVDs was 14.4 per 100,000 flying hours (over 6 times higher than the SD accident rate during day flight). Although NVDs are an enormous advantage and have revolutionized military flight operations, they do have limitations, and the increased risk of SD is arguably the most significant. Therefore, it is recommended that the increased risk of SD during NVG flight should be specifically emphasized during training and mission planning.

9.2. Helicopter operations in snow and dust.
Only the U.S. and British Army routinely address this issue (the hazard of which is also known as "whiteout" and "brownout" respectively. However, training tends to be academic rather than "phenomenological" and so the following recommendations are made:

a. Training objectives to avoid and manage SD during brown out / white out are established.

b. The increased risk of SD in this hazardous environment flight should be specifically emphasized during training and mission planning.

9.3. Weapons Delivery.
SD and target fixation are hazards during strike aircraft bomb operations, especially when target designating using FLIR or other targeting pods that provide alternate perspective views. Again, the hazard tends not to be mentioned during flight training. This form of SD may be caused by a design flaw in the various targeting systems. If so, it is recommended that this situation be corrected. Nevertheless, the risk of SD should be stressed during weapons delivery training.

9.4. Carrier operations.
Catapult launches are very disorienting and have caused mishaps, especially at night. In these cases, it has generally been apparent that the pilot was using visual cues during take-off rather than instruments. Further emphasis on the awareness of the disorienting phenomenon is required.

9.5. Formation flying and in-flight refueling.
Formation flying and in-flight refueling , particularly at night, have been associated with an increased risk of SD. Again, the increased risk should be emphasized during specific operation training.

10. SD TRAINING FOR ASSOCIATED AVIATION PERSONNEL

10.1. Review.
For aircraft that employ non pilot personnel in the crew (e.g. engineers, radar operators, and loadmasters) there is a variable amount of training in SD. This is particularly important when addressing SD illusions that are more likely to be reported by crew in the rear of transport and command aircraft.

10.2. Recommendations.
Crew in the rear of the aircraft could benefit from more emphasis of the SD hazard. It is also recommended that training for non-pilot crew is coordinated with existing pilot SD training so that experiences may be shared and crew coordination thus enhanced.

11. TRAINING THE SD TRAINERS

11.1. Review.
A common theme throughout the review was that the quality of SD training varies depending upon the trainer. In many cases flight surgeons are over-tasked, and it would be unrealistic to involve them more in SD training. Nevertheless, training in aeromedical topics is one of their responsibilities. Flight Physiologists, where established, are probably more appropriate trainers for this task, but they do not always working closely enough with the operational forces. The training they in turn receive is probably adequate, but requires updating more often. Trainers should also be encouraged to include more new topics during refresher training in SD. There was also an agreed opinion that the TWG subgroup proceedings may be misinterpreted as recommending the augmentation of **existing** training too much, when perhaps the emphasis should be on changing training to make it more efficient by using new audio-visual and simulation technologies. If the latter is to be implemented, there will be a need for better dissemination of information directly from the acknowledged experts to the trainers via Internet and video, etc. The subgroup also agreed that teaching

material is not updated often enough. In particular, lessons learned from mishaps and incidents should be disseminated at the earliest opportunity. Information input to a central site, and further distribution could be arranged for each service's aeromedical school, research laboratory and Safety Centre. Links should be established with these agencies and other Aviation Medicine web sites. There is also a need for a "feedback relationship" between the research and training communities, particularly as new and technologically advanced simulators come on line throughout the military. Examples of cooperation include: avoiding the designation of a particular device solely for training or research, and including trainers and researchers in device planning meetings.

11.2. Recommendations.
The following recommendations are made

a. Each service should provide information to a central site on their ideas of the type of information that should be available on an Internet web site.

b. Videos with a training value should be collated, reviewed, and those approved should be listed on an Internet web site.

c. SD trainers should be encouraged to video tape their own lectures. These could then be reviewed, and listed on an Internet web site.

d. SD trainers should be encouraged to observe other service's training sessions and send videos of their own sessions to colleagues.

12. CONCLUSION

12.1. This review has addressed training as an appropriate, and eminently affordable countermeasure to the continuing hazard of SD. This does not necessarily imply that training is the only, or even the preferred solution to the various problems associated with SD in military aviation. Nevertheless, where training can help, it must be regarded as the most readily applied control.

12.2. The single most important training recommendation is "to make training more experienced-based." This essentially implies more simulator and in-flight demonstrations, and SD preventive and management procedures. The best way to make aircrew aware of SD and give them strategies to recover, is to give them as real an experience as possible.

12.3. It is most heartening to see that the recommendations of the TWG subgroup have already been incorporated in a national implementation document [18].

13. ACKNOWLEDGMENTS

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High Fidelity Survival Training For Ditched Aircrew and Passengers

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Introduction

When Survival Systems was established in 1982, it was decided that the sole purpose of our existence was:

To enhance and preserve workers' lives through safety education, training technologies, and applied research and development.

The principle people at risk were those that flew over water for a living whether pilots, crewmen, or passengers. It was decided to focus on emergency evacuation training for them.

To be global leaders in our work (our service) required that we needed to enroll not only our clients, but also our own people in an exciting, seemingly unreachable, significant vision.

The end result of this strategic intent would affect every human being who may have to react to, escape, egress from, affect a rescue, or survive a life-threatening situation over water or on land worldwide.

It was determined that the global standards we were attempting to establish in every case would include practical training, the most modern equipment and simulation technologies, and the research and development conducted to maintain this global market leadership.

Survival Systems Limited's strategic objective was to:

Create, set, and maintain the standard or measurement by which all aircrew and passengers (fixed wing or rotary wing) (military or civilian) in the world will be trained to survive an emergency ditching or crash situation.

Over a decade ago, Survival Systems adopted the premise that egressing a downed, flooded helicopter is a survivable event. Further, a trainee success rate approaching 100% in actual emergency egress situations could be achieved with a training protocol that replicated all variables of a true ditching. In addition, it was believed that through learned emergency response techniques, aircrew and passengers could significantly reduce ditching impact injuries.

High-fidelity training programs were designed to prepare an individual to save his / her own life and the lives of others. Our team holds a moral obligation to ensure that trained aircrew can survive actual emergency situations. Survival System's original ditching training programs were developed for civilian, offshore workers. Their companies, concerned with operational efficiency, insisted on absolute safety, ease of personnel training, and as close to 100% successful course completion as possible.

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Failure to successfully complete any training component was unacceptable because workers' employment depended on having valid training certification. In order to satisfy this requirement, intense training for the worst case scenario became the norm. To minimize any failure rate, and to ensure that even the least proficient trainees met required performance standards, the number of training sequences performed was increased by 30% from the initial training courses.

To achieve training excellence, Survival Systems initially relied heavily upon input from experts in the fields of human factors in aviation and marine physiology, psychology and ergonomics. In addition, empirical data has been recorded over the years from approximately 120,000 successful trainees, and approximately 600,000 Modular Egress Training Simulator (METS™) training sequences performed to date.

To train aircrew and passengers to survive a ditching situation meant that disorientation had to be induced during training. Therefore, physical disorientation needed to be created during the simulated emergency training.

It was determined that in an actual ditching, the crew and passengers' ability to make a good practical survival decision will be confused with many different sensory inputs including false information from the organs of the inner ear. This ultimately could lead to disorientation and drowning.

Safety statistics, training observations, and interviews with aircrew and passenger survivors demonstrate that the causes of underwater disorientation are multi-faceted, and their interaction is highly complex. Some of the factors that make underwater disorientation better or worse include the following:

- rate of downward acceleration during descent and the force of airframe / surface impact;
- speed of rotation in two-axis seating facing forward, backward and sideways;
- loss of visual cues;
- loss of gravitational cues (especially foot and seat of the pants);
- ingress of water into the mouth or nasal cavities (particularly in an inverted position);
- hydrostatic pressure on the body and its impact on sensory output;
- effect of buoyancy on gravitational inputs;
- violent ingress of water into the fuselage and its effect on the body;
- terrifying psychological effect of the potential of drowning;
- previous alcohol ingestion;
- previous diving experience;
- rotation of the fuselage with true or false cues being transmitted to the organs of balance;
- contact and accelerating injuries;
- previous training effect; and
- swimming ability.

Below is a summary of reasons for difficulty during egress courtesy of the United States Navy Emergency Helicopter Underwater Escape Statistics from 1982 to 1985. (The percentages have been rounded off for presentation.)

Reason For Difficulty	Percentage Who Experienced Difficulty
Inrushing water	14.2
Reach exit, aircraft attitude	11.7
Dark, no visual references	11.4
Confusion, panic, disorientation	10.2
Hampered by equipment	7.7
Reaching exit, equipment	7.0
Hampered by injuries	7.0
Releasing exit	5.7
Unconscious, dazed	5.7
Release exit, obstructed	4.2
Release restraint	3.5
Fire, smoke, fuel	3.2
Unable to open exit	2.5
Reach exit, injury	2.5
Pinned in aircraft	2.2
Cold	1.2

During normal flight, an aircrew member's ability to perceive orientation in three-dimensional space depends on a learned ability to interpret the continuous input of signals from many sensory receptors. Some of these receptors are grouped together to form a specialized sense organ, like the eye, or the vestibular apparatus of the inner ear. Others are more generally distributed in the body and are found in skin tissue and joint capsules and supporting tissues. In a natural environment, adequate and accurate perception of our own body's spatial orientation relative to immediate surroundings is primarily achieved through visual cues. These cues, along with cues from non-visual receptors, allow for a sense of position, attitude, and motion relative to a stable frame of reference, namely the earth's surface and gravitational vertical.

However, in a downed, sinking helicopter rotated by waves, wind, and the gyroscopic effects of rotating blades, understanding which way one is facing in the seat, if indeed there is any seat left, is problematic. The helicopter airframe, being dominant in immediate surroundings, has changing orientation relative to the earth's surface and to the gravitational vertical, and may have become badly distorted and not represent the pre-impact shape. As the helicopter inverts, visual cues disappear, or at best are distorted by water, fuel, oil, debris, bubbles, and floating objects. Therefore, visual cues cannot be relied upon to ascertain one's spatial orientation.

> *Failure of non-visual sensory systems that detect attitude or motion changes of a sinking helicopter is probably the single most important cause of orientation error experienced by escaping aircrew.*[1]

> *Man has no absolute sense of his position, nor of his velocity within the spatial coordinate system . . .although he can sense change in position and velocity by detecting the angular or linear acceleration associated with the movement.*[2]

Humans can perceptually integrate information provided by the stimulated receptors so that reasonably accurate assessments of the magnitude in position change can be made. However, the foregoing is true only for stimuli that are above the detection threshold and within the dynamic range of the sensory system, and the organs of balance are notorious for giving false information.

Threshold values have been determined in laboratory experiments where the subject's sole task was to detect motion stimulus. The following illustration identifies these figures.

For angular moments of short duration (not greater than 5 seconds), the angular velocity must exceed 0.2 - 8.0 deg / sec. Sustained angular acceleration has a threshold of 0.3 deg / sec squared. The threshold for detection of linear acceleration has been found to be in the range of 0.3 - 0.2 m / sec squared and when acceleration is applied for less than 5 seconds then the linear velocity must exceed 0.3 - 0.4 m / sec for motion to be perceived.[1]

A Practical Experiment to Identify the Human Factors of Escape

In an effort to measure the physical and ergonomic factors affecting emergency egress, a research and development project was completed by Survival Systems Limited in conjunction with Energy Mines & Resources Canada[3]. Two hundred and thirteen (213) subjects were recruited to examine the factors that might impede or improve an individual's ability to successfully egress during an emergency ditching. The factors that were found significant were: seat position, exit type, visual deprivation, and subject task knowledge. The result of the study prompted Survival Systems to refocus on classroom training and practical skills acquisition. One

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[1] Brooks, Capt (N), C. J., To Survive A Helicopter Accident the Crew and Passengers Must Think and Act Defensively: Presented at the International Rotary Wing Safety and Life Support Symposium, London, UK, 29-30 October 1992, pp. 17-18.

[2] Ernsting, J. and King, P. J., "Mechanisms of Orientation in Flight", Aviation Medicine: Butterworth-Heinemann, ISBN 0-407-01470-5, 1988, p. 429.

of the most important outcomes was that Survival Systems' long-held belief was confirmed C training must include use of a high-fidelity training simulator that incorporates exits designed to replicate those of an actual helicopter.

Indeed, these factors provided the rationale for phenomena observed over the years by Survival Systems' instructors during emergency egress training courses. For instance, the difficulty experienced during an egress in most cases is directly related to the position of the seat relative to the exit.[3]

A seat beside an open exit provides the greatest probability of survival. Chances of survival decrease with increased distance between seat and exit. Chances also decrease if the exit window or door is in place. Any directional change required by aircrew during egress significantly increases the risk of severe disorientation and failure to egress successfully, whether it be a 90E shift to move across an aisle, or a 270E turn to move aft from a forward-facing seat. A seat positioned directly in line with an exit is a distinct advantage; it allows the passenger to "fix" the egress route in mind as the helicopter ditches. Findings outlined in the Review of Helicopter Offshore Safety and Survival recommend *...that training should continue to stress the importance of concentrating on the nearest jettisonable hatch or window in a crash.*[4]

Speed of Training

The United States Army reported an increase in trainee performance when training sequences are run faster than real time.[5] The artillery corps measured scores obtained from two groups of students. The first group was trained in real time while the second group was trained at a rate 25% faster than real time.

The second group achieved a performance increase of 50% over the group trained in real time. Objective measurements for both groups were made with the United States Army *Gunnery Index.* The increase in performance is significant.

The United States Army has documented evidence to indicate that performance is enhanced through the manipulation of *simulated time*[6]. The learning rate improves through the intensification and acceleration of task interaction at a faster than normal time.

NASA reports that their test pilots perform better in actual test flights using new equipment after they have been trained at a rate faster than real time[7]. Test pilots in the 1960's complained that events in actual test flights seemed to occur at a faster rate than in simulated situations. Since the sixties, NASA has regularly trained

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[3] Canada Oil and Gas, Lands Administration; Energy, Mines and Resources Canada; and Indian and Northern Affairs Canada, Factors Affecting Egress From a Downed Flooded Helicopter: Technical Report 109, February 1991, p. 78.

[4] Civil Aviation Authority, Review of Helicopter Offshore Safety and Survival, London, February 1995, p. 23.

[5] Military Simulation & Training - MST, ISSN 0937-6348, Issue 2, 1995, p. 31

[6] Military Simulation & Training - MST, ISSN 0937-6348, Issue 2, 1995, p. 31

[7] Military Simulation & Training - MST, ISSN 0937-6348, Issue 2, 1995, p. 31

pilots using accelerated time frames. Improved subject response time and less frequent errors are reported in all scenarios.

Documented evidence from the United States Army and NASA supports the effectiveness of training at above real time in simulated environments. Survival Systems Limited has adopted these same principles and uses worst case, real time frames in certain training sequences such as; exits in place, blocked or jammed exits, cross cabin movements, multi-personnel egress through one window, and monkey tail disengagement. Since ditching training involves the development of psycho-motor skills, it is logical to conclude that helicopter emergency egress training is enhanced in as close to real time worst case accident training scenarios.

Modular Egress Training Simulator (METS™)

A strong parallel exists between current use of high-fidelity simulation in areas of flight training and emergency egress training. Considered the father of flight simulation, E. Link successfully persuaded a cynical Army Air Corp to invest in flight simulators for training in the 1930's.

Link understood that trainee acceptance of flight simulators was critical to successful training. He placed stubby wings and squadron insignias on the sides of his boxes attempting to increase training fidelity in the minds of user pilots.

Since Link's time, advancements in aircraft and aircraft simulator designs have gone hand in hand. Modern flight simulators vary from small, micro processor-based, table-top trainers to large cockpit replicas following a precise flight profile by powerful hydraulic legs and controlled by sophisticated computers.

Flight simulator fidelity is directly related to training tasks. Certain tasks such as engine start, systems operation, malfunction diagnosis, and many instrument procedures, can be effectively taught with low-fidelity devices. These relatively simple devices yield appropriate scales of realism required for the training task at hand.

Due to inherent safety requirements, armed forces worldwide demand that critical tasks, such as takeoff and landing, emergency flight operations, or combat mission rehearsals, entail the highest level of simulator fidelity reflective of an actual aircraft. Clearly, simulation of life-threatening situations, such as emergency egress from a downed helicopter, deserves no less than full application of this practice.

Why the Modular Egress Training Simulator (METS™)?

In 1987, because of a desire to deliver truly realistic training and recognition that a void in the world marketplace existed, Survival Systems embarked on a development project to construct a ditching simulator that offered *aircraft-specific* training options.

The METS™ was designed to meet this simulation demand. Among other specifications, the design criteria required simplicity, low cost, and robustness, with minimal maintenance on a continuous, year-round basis. The specifications also called for the METS™ to be installed in an already-existing training pool rather than require its own exclusive-use or specialized pool.

The METS™ was designed to be the central component of a systems approach to emergency egress training. The key word, modular, means that the METS™ can be configured to represent any helicopter in the military or civilian inventory.

Survival Systems developed high-fidelity simulation equipment and training methodologies to represent each of the life-threatening scenarios encountered in a helicopter ditching from strap-in on the ramp to rescue after the accident. Training sequences cover a variety of crash scenarios involving blocked exits, blackout conditions, and smoke. The end result after training is that trainees are confident and capable of affecting their own egress following a helicopter crash. Proof that the training is doing what it is supposed to do is that ten (10) aircrew have already testified that they have survived an actual helicopter ditching because of the aircraft ditching training they received using the METS™.

Survival Systems Group

METS™ Success Stories

While the aircraft was in the process of capsizing, I followed the step-by-step egress procedures taught by Survival Systems. I found that although disoriented and in a stressful situation, the training quickly came back to me and the whole evacuation was just like another run in the METS™.
✈✈ CH-124 Sea King ✈ Capt PE Hitchcock ✈ 27 February 1993 ✈ Gulf of Mexico

Simply put, without your course, I might not have survived my first major deployment. The methodical yet realistic training process employed by Survival Systems staff gave me the edge I needed to stay alive in an all-too-real ditching emergency.
✈✈ CH-124 Sea King ✈ Lt J Tasseron ✈ 27 February 1993 ✈ Gulf of Mexico

An unexpected benefit of the training was my ability to cope with the stress and fear associated with such an incident occurring at night in heavy seas. This course should be mandatory for anyone involved in helicopter over-water operations.
✈✈ CH-124-A Sea King ✈ MCpl DJ McDonald ✈ 27 February 1993 ✈ Gulf of Mexico

Your training is so realistic that to appreciate the value of your techniques, one has to survive a real situation. It saves lives.
✈✈ CH-124 Sea King ✈ Capt S McLean ✈ 27 February 1993 ✈ Gulf of Mexico

I have been flying for 17 years, both civilian and military. I have done many practice bailout/ditching exercises, but no other training could have better prepared me [for the crash] than what I was taught at Survival Systems.
✈✈ CH-124 Sea King ✈ MCpl Gerry Corrigan ✈ 4 August 1991 ✈ Schnetecdy, New York, USA

I would like to thank you for the excellent and very realistic training that you provided us with. This training saved our lives. The sensation of water rushing in was very similar to the one that was simulated in the dunker training; recall of this training allowed us to follow through with the proper sequence of actions and successfully egress the aircraft which had rapidly filled with water.
✈✈ Bell 412, Griffon ✈ Capt KR Krey, Capt SW Pelly, Sgt SD McCoy, MCpl JBA Daigle ✈ 12 November 1996 ✈ Northern Labrador, Canada

Because of the information I received from Survival Systems regarding proper evacuation procedures, I was able to avoid panic, I knew exactly what to do and had planned my escape procedure in advance.
✈✈ Bell 206 ✈ Robert Thorne ✈ June 1995 ✈ British Columbia, Canada

My first thought was "Okay, I know how to deal with this". As I cleared my exit, undid my harness and moved toward the surface, the second thought to run through my mind was, "I knew the egress course would be worthwhile, but I didn't expect to use the training within 36 hours of completing it!"
✈✈ CH-136 Kiowa ✈ Capt KH Jones ✈ 15 June 1995 ✈ Lake Simcoe, Ontario, Canada

Current literature reinforces the importance of realistic training for experienced aircrew who fly over water frequently. Much more transfer of training occurs when the training simulation offers a high degree of realism, students are more apt to accept its validity and benefit from the training. A generic training environment is seen as having low value.

The METS™ provides trainees with an authentic, high-fidelity environment in which to practice emergency surface evacuation drills and underwater escape techniques.

The great advantage and novelty about the METS™ is that it is modular. It is capable of being transformed very quickly into many different aircraft types in a ditching scenario. From an operational viewpoint, this means that the simulator can be configured to represent different helicopters and fixed wing aircraft such as the Lynx, Gazelle, Puma, Beech, and Hercules C-130. (Additional emergency exits and interior equipment can be purchased separately at any time if the customer reconfigures their fleet cabin or fuselage arrangements.)

Currently, Survival Systems manufactures 64 different emergency exits for 15 helicopter and fixed-wing aircraft types. These configurations incorporate the use of exterior panels replicating emergency exits found on specific aircraft. Additionally, the framework of the simulator allows for placement of interior bulkheads and other appliances, such as crew stations and troop seats, to conform to the size, utility, and configuration of the aircraft types most commonly used by the customer.

Since the METS™ incorporates replicas from simple to complex exit systems on actual aircraft, safety and durability is foremost in the simulator design. Based on training data submitted by our clients, as of this date, no training center using our METS™ has ever cancelled a day of training due to any un-serviceability of the METS™. Operationally, the METS™ has been designed and manufactured to provide years of reliable service with low maintenance.

Safety of the METS™ and METS™ Training Capabilities

The METS™ operates on a simple physical principle of weight over buoyancy. It, therefore, requires minimal infrastructure to install and begin training. One of the critical operating differences between the METS™ and other ditching simulators is that there are no cables or mechanical hydraulic systems involved in rotating the device. Thus, the trainee or diver cannot become entangled.

An additional feature is that the free-wheeling variable free rotating feature of the trolley allows for a greater degree of simulation fidelity than is possible with cables.

Many aspects of the METS™ make it a fail-safe simulator system. The following aspects, or special features, bring safety to the forefront in Survival Systems' manufacturing, operating, and training processes.

a) The simulator framework, coupled with the modularity of interior and exterior components, allows for an infinite number of simulated aircraft configurations. These configurations can be set up to allow optional egress openings when working with trainees who are experiencing difficulty with the underwater escape techniques.

b) The simulator is constructed of materials, and fabricated in such a manner to minimize any sharp edges, corners, or other protuberances that might cause injury to personnel above, on, or under the surface of the water.

c) While training subjects are inside effecting an egress exercise, the simulator can be raised out of the water (15 - 20 cm) in order to create a safety air gap inside the simulator. This feature makes EBS training possible in the METS™. The air gap is adjusted to maintain the required safety maximum depth of 3.7 feet at mid thorax as required by the US Military and Canadian Forces.

d) There is adequate room inside the METS™ for trainees and instructors to move about safely.

e) Each emergency exit is operable from both inside (trainee subject / instructor) and outside (safety diver / safety technician) the simulator. These release devices are simple to operate and are clearly marked. A fail-safe mechanism is built into all emergency exits so that, if required, a safety diver can operate them and / or override trainee actions.

Although the METS™ incorporates exit systems replicating those of actual helicopters, training can be conducted with or without exits in place. Thus, if lower training fidelity is all that is required for a given training scenario due to time constraints or other factors, such as trainee type, training can be accomplished without emergency exits.

f) All seating restraint systems (2-, 3-, 4-, 5-point harness systems) replicate those found in the actual helicopter or aircraft. Each one, for safety purposes, incorporates a separate emergency release system which is easy to locate and simple to operate.

g) The simulator incorporates simple, sturdy, robust windows, doors, and other emergency exit fail-safe apertures maintaining the safety of the trainee. These devices are built for repetitive use in a rugged training environment.

h) The simulator rotation system incorporates a back-up, fail-safe suspension system to eliminate trolley departure from the rotation ring in the event of primary trolley wheel failure. Both of these components have been tested by the Nova Scotia Research Foundation to withstand over nine (9) times the maximum rated load of the simulator. The Foundation also cycle tested the trolley to simulate 20 years of continuous METS™ use in typical training mode operations. No failure of trolley components was experienced in either test.

i) The simulator rotation system incorporates a "rotation arrest brake". This allows the METS™ rotation to be stopped at any angle up to 220°or any time while the simulator is being lowered into the water. The brake is also operable during all phases of the training sequences.

j) Years of product development and refinement have produced a simulator that requires very little maintenance. There is no requirement for any overhaul during the life of the simulator.

k) All components are made from plastic, coated aluminum, and stainless steel for two reasons. First to prevent the corrosive action of the chlorinated water, and second to eliminate any chance of components dissolving in the water and producing a toxic hazard.

Training Scenarios

Multiple scenarios can be staged as ditched helicopters often roll 90E and stop momentarily prior to sinking and inverting completely. The types of training exercises that can be performed using the METS™ include the following:

- Inversion scenarios replicated from actual ditchings can be simulated with ease. The METS™ rotation is buoyancy-induced and non-mechanical. Therefore, a trainee can never predict the rate or direction of rotation prior to the sequence or during the rotation inversion process;
- Hover abandonment;
- Surface evacuation;
- Partial / off-angle submersion;
- Upright and inverted evacuation with casualties;
- Inverted egress - exit in, exit out;
- Inverted with EBS / HEEDS - spare air;
- Cross cabin - left, right;
- Liferaft / emergency equipment retrieval;
- Night and smoke exercises; and
- The METS™ can be used as a scientific tool to investigate many different previously unanswered questions such as how much buoyancy in an immersion suit will limit successful escape, or what roll and descent rate produces the most effective disorientation

METS™ Project Rationale

The METS™ is a proven training simulation system successfully used around the globe by both civilian and military training centers. It evolved from an initial design in 1987. A prototype located at Survival Systems in Dartmouth, Nova Scotia, Canada, and two initial production models, shipped to Australia, were the first to be manufactured. A third production model was manufactured and installed in Den Helder, The Netherlands.

Each of the first three (3) METS™ production models incorporated many new advancements compared to the initial prototype. However, improvements and refinements continued to be made until the fourth model was manufactured. Production model number four (4) was the first one to include all the advances in technology from the first three models. This has been the basic template for design of all the remaining systems in service. This simulator is located in Bergen, Norway.

Additionally, nine (9) METS™ Model 30 simulators have been sold to clients in the United Kingdom, Holland, Norway, the United States, Indonesia, Brunei, Australia, and there is one at Survival Systems' training facility in Dartmouth, Nova Scotia. The Model 30 METS™ (Figure 1) is well suited for such helicopters as the Puma and the Sikorsky S-61. Survival Systems' last sale of a Model 30 METS™ was to the Republic of Korea Navy in September 1997.

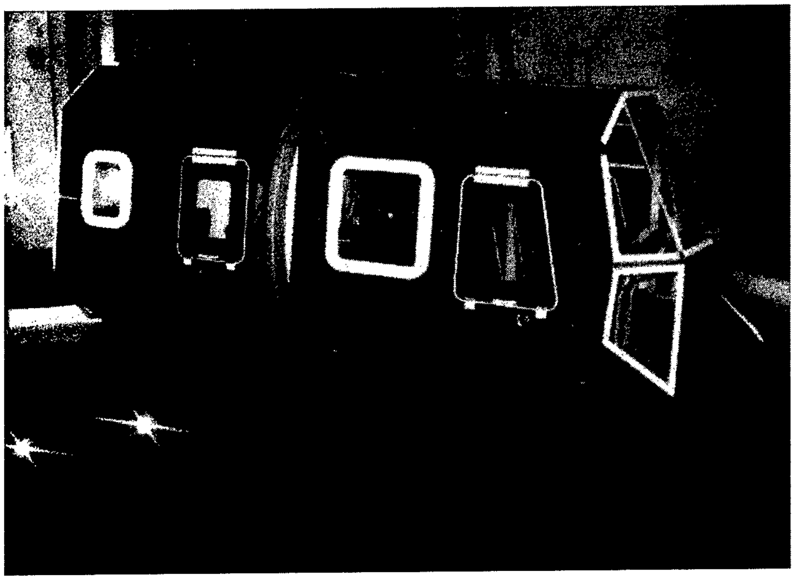

Figure 1 - Modular Egress Training Simulator (METS™) Model 30

With the exception of the Royal Netherlands Air Force and the Republic of Korea Navy, these simulators have all been sold to commercial training companies. However, all other clients train military personnel (Canada, Norway, United Kingdom, Holland, Indonesia, United States, Brunei, and Australia).

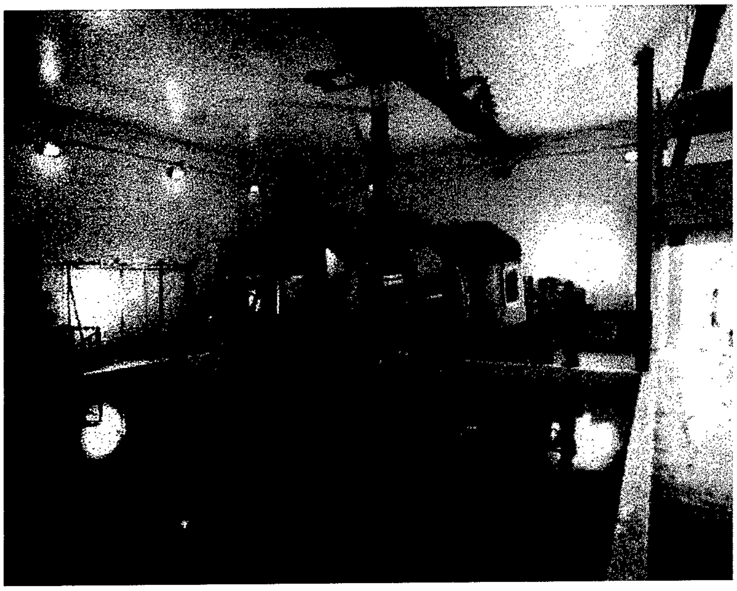

Figure 2 - Modular Egress Training Simulator (METS™) Model 40

In 1995, Survival Systems realized the need for a larger, wide-body variation of the METS™ Model 30 and, therefore, designed and built one (1) METS™ Model 40 (Figure 2). This model has now been in operation at the Dartmouth, Nova Scotia training center for over one year. This has the distinct advantage that it can also be used as a fixed-wing aircraft-ditching simulator for aircrew and flight crew.

Survival Systems recently delivered Apache Cockpit Modules (ACM™) (Figure 3) to the Royal Netherlands Air Force. The ACM™s are designed to be used in conjunction with either the METS™ Model 30 or Model 40. The METS™ serves as a rotation vehicle for the smaller Apache Cockpit Modules. A stand alone Apache / METS™ has now been built. Preliminary research and development trials were conducted for the British Army and the first Apache METS™ is now in use on contract with the United States Army in Fort Rucker.

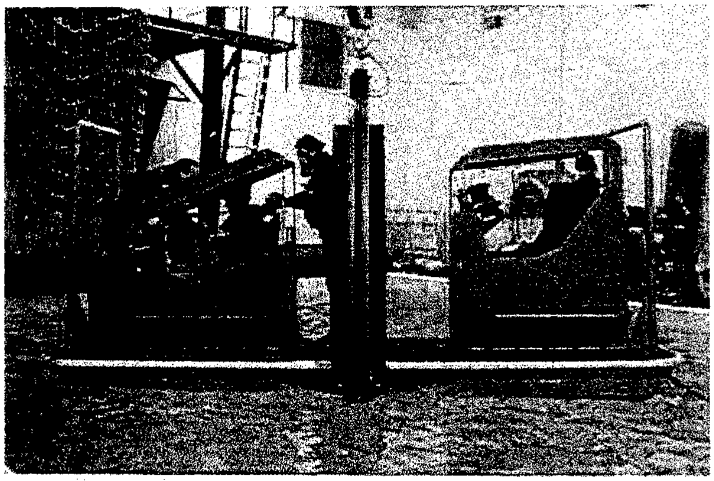

Figure 3- Apache Cockpit Module (ACM™)

Due to the market demand a smaller METS™ than the Model 30 was required . As a result the METS™ Model 5 is the most recent training simulator. The Model 5 incorporates all of the Model 30 features within a slightly smaller body. This small-bodied version replicates the operational environment of helicopters such as the Lynx, Gazelle, Dauphin, Bell 206, and MBB-105. Survival System's last sale of a Model 5 METS™ was to Esbjerg Brandskole, a Danish training centre in August 1998.

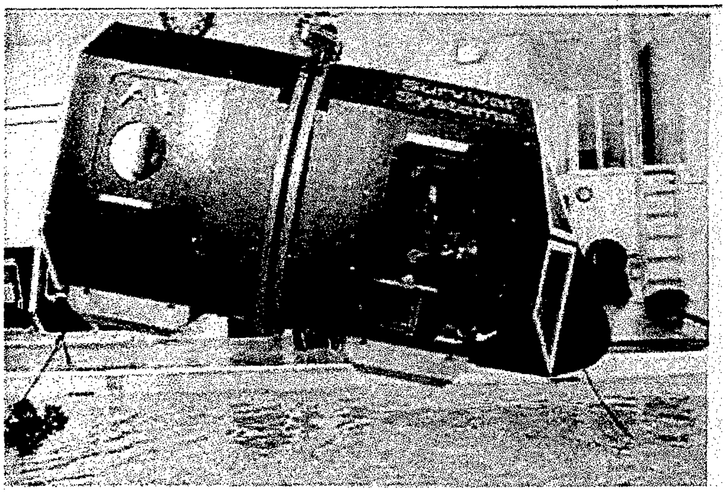

Figure 4- Modular Egress Training Simulator (METS™) Model 5

Today there are a total of sixteen (16) working METS™ working in ten (10) countries and on four (4) continents.

Currently under development is a computer-controlled, motorized ring that will allow for greater trolley rotational control. The METS™ Model 40 is designed to be easily retrofitted with this new technology once it is proven.

METS™ as a Research and Development Device

Survival Systems is committed to providing the best possible instruction in emergency underwater escape training. To reach this goal, the METS™ has been specifically designed to simulate specific aircraft configurations in ditching situations. A natural extension of this training relates to the trials and evaluations on hazards, egress, and procedures relating to the improvement of onboard aircraft safety. Research and development projects that Survival Systems has been involved with during recent years include:

a) ***To Develop a Procedure / Protocol for the Transport of Medical Evacuees by Helicopter from an Offshore Platform to Shore-Based Facilities:*** Specific problems attending a helicopter medical evacuation flight in the event of a ditching were examined. Attention was given to parameters such as stretcher size, weight, and configuration vis á vis exits, attendant handling, life raft compatibility, patient dexterity, wave and thermal protection, and flotation considerations.

b) ***The Ergonomics of Jettisoning Escape Hatches in a Ditched Helicopter:*** This study represented the first formal investigation of the problem of location, operation, and jettison of escape hatches[8]. Results revealed many unforeseen problems. Specifically, there was no

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[8] C.J. Brooks, A.P. Bohemier, G.R. Snelling. The Ergonomics of Jettisoning Escape Hatches in a Ditched Helicopter. Aviat. Space Environ. Med. 1994 65: 387-95.

standardization of hatches and levers in that there were problems with location and operation of levers due to poor design. No human engineering study has yet been conducted to investigate the problem. From this work, the policy of underwater escape training with emergency exits in position must be mandatory for all who fly offshore.

c) ***To Establish the Maximum Inherent Buoyancy for Passenger Helicopter Survival Suits:*** The buoyancy of trapped air in between each layer of clothing and of deliberately trapped air in foam rubber type immersion suits for hypothermia protection are added to the inherent buoyancy of each individual[9]. The total buoyancy may indeed be of such a high value that it decreases or could even prevent the ability to make an escape from an inverted cabin. Four (4) experiments were conducted in the METS™ to establish a new Canadian General Standards Board standard.

d) ***Emergency Breathing Systems (EBS) as an Aid to Egress in the Modular Egress Training Simulator:*** The object of this study was to determine to what extent the EBS would be a useful addition to the inventory of survival training equipment provided for helicopter passengers flying offshore[10]. The emphasis was on technical advantages and disadvantages.

e) ***Seatbelt Trials (Military):*** This trial examined the extent of effectiveness that military personnel egress from a proposed new seatbelt configuration in a helicopter ditching. Current seatbelts were used as a control study.

f) ***Military Emergency Breathing Systems (EBS) Evaluation:*** This military program examined various emergency breathing systems to ascertain the one most appropriate for Canadian Forces personnel use. Factors taken into consideration included ease of operation and most importantly, reliability.

g) ***New Ship-Borne Aircraft (EH101) Port Side Cabin Operator, Emergency Egress Trials:*** This trial evaluated the ability of an operator, sitting in the port seat, to egress from the aircraft via the primary exit for an uncontrolled ditching situation.

h) ***Factors Affecting Egress from a Downed Flooded Helicopter:*** This project examined several factors that could affect a passenger's chances of surviving an offshore helicopter ditching - all had to do with aspects of safely exiting the stricken helicopter[11].

i) ***Helicopter Door and Window Jettison Mechanisms for Underwater Escape: Ergonomic Confusion!:*** There are 23 different door, hatch, and window release mechanisms identified in 35 types of helicopters that earn their living over water. There is no standardization of the mechanism within each cockpit or among helicopter types, nor is there any standardization of the location relative to the operations, whether the mechanism matches the task or in which direction

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[9] Brooks, C.J., Potter, P.L. The Establishment of 137N as the Canadian General Standards Board Maximum Acceptable Inherent Buoyancy Limit for Passenger Helicopter Suit Systems. Annals Physiol. Anthrop. Vol. 5 No. 3 1986.

[10] Bohemier, A.P., Chandler, A., Gill, S. Emergency Breathing Systems as an Aid to Egress From a Downed Flooded Helicopter. COGLA Report. No 108 May 1990.

[11] Bohemier, A.P., Chandler, P., Gill, S. Factors Affecting Egress from a Downed Flooded Helicopter. COGLA Report No. 109 February 1991.

the door / hatch / window is jettisoned. New regulations are needed by military and civilian authorities to address the ergonomic confusion.

j) ***The Evaluation of a Series of Mechanisms for Jettisoning a Window / Door in a Flooded Inverted Helicopter - Ultimate Emergency Helicopter Exit Trials:*** A simplified, universally retrofitable helicopter emergency exit has been designed and manufactured[12]. Phases I, II and III were completed by survival Systems in conjunction with the Defence and Civil Institute of Environmental Medicine. Phase IV (examination of the lighting system in bright ambient daylight conditions) is currently in process. The Canadian Forces will share patent rights with Survival Systems Limited, and Survival Systems will market these emergency exits worldwide to civilian and military helicopter operators.

The METS™' technology is continuously updated, and new features are offered to training centres as soon as they become available. A mechanical engineering team is employed full-time and continuously interacts with training instructors to ensure on-going innovations and improvements are made to the METS™.

Feedback from both research and development and training instructors is an important part of the training development process, as it is in all areas of Survival Systems' training operations. Success of the METS™ training system can be measured by its worldwide recognition as state-of-the-art emergency egress technology.

Following is a testimonial from a Canadian Navy Sea King (H-3) aircrew member who was involved in a ditching off the coast of Florida in February 1993. His letter is very typical of those received after incidents involving the trainees.

It reads:

For a moment I saw certain death when I realized I was trapped upside down in my seat. Somehow, the training I had received took over. The same way I had done it in the trainer four years before, I successfully escaped. I owe my life to your training and your staff.

Your training is so realistic that, to appreciate the value of your techniques, one has to survive a real situation. Your training is a requirement for anyone involved with overwater operations. It saves lives.

Captain S. McLean
Crew Commander
Sea King Ditching February 1993

This incident reinforced a lot of our research and training techniques.

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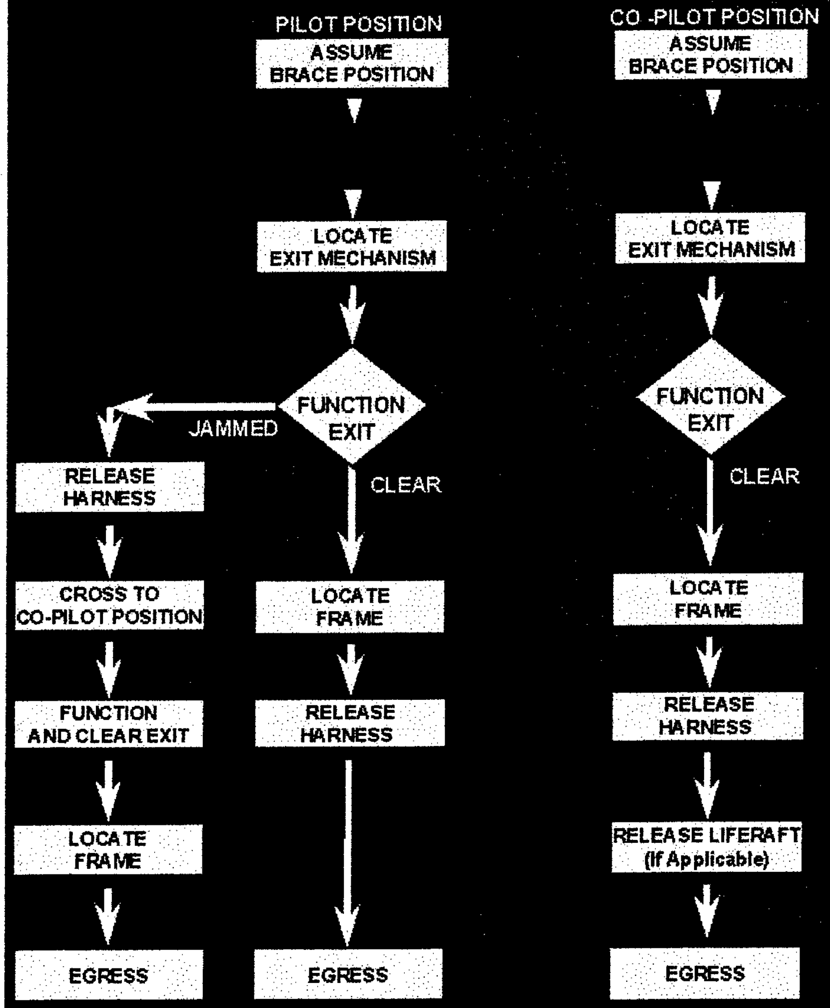
[12] Brooks, C.J., Bohemier, A.P. Helicopter Door and Window Jettison Mechanisms for Underwater Escape: Ergonomic Confusion! Aviat. Space Environ. Med. 1997; 68:844-57.

It was only after training thousands of aircrew that we understood clearly an egress sequence was not a single movement or a single procedure. Based on the seating position and the distance of the aircrew from the emergency exits; it was determined that egress is more of a series of steps almost like a computer program that one has to follow and deliver on to successfully egress. The following flow chart demonstrates this (Figure 4).

Surviving a Helicopter Ditching

PILOT - METS™ EGRESS



PILOT POSITION

- ASSUME BRACE POSITION
- LOCATE EXIT MECHANISM
- FUNCTION EXIT
  - JAMMED
    - RELEASE HARNESS
    - CROSS TO CO-PILOT POSITION
    - FUNCTION AND CLEAR EXIT
    - LOCATE FRAME
    - EGRESS
  - CLEAR
    - LOCATE FRAME
    - RELEASE HARNESS
    - EGRESS

CO -PILOT POSITION

- ASSUME BRACE POSITION
- LOCATE EXIT MECHANISM
- FUNCTION EXIT
  - CLEAR
    - LOCATE FRAME
    - RELEASE HARNESS
    - RELEASE LIFERAFT (If Applicable)
    - EGRESS

VA 1

If an aircrew missed any critical step during egress, potential death would occur. We studied egress sequences, underwater movement, body rotations, hand / head movements and developed critical processes that, if utilized, would lead these aircrew to successfully egress. It is complicated but also in a sense simple. It is a repeatable physical skill that we teach in the end.

The principal author had conducted the training for Captain McLean and after his crash Captain McLean told the author that when he took the training four years prior, he could not understand why we did this training the way we did. He said he understood the realism of the simulator but did not understand the teaching techniques. Indeed, he felt somewhat bitter that the training was so difficult for him physically and psychologically.

What he did not understand and what we had understood through research and development was that inducing disorientation was only part of the training.

In a very real sense, our common enemy is ultimately the sea. Aircrew and passengers flying over water continually face the danger of ditching. Edmund Burke said two hundred years ago, *"He that wrestles with us, strengthens our nerves and sharpens our skills. Our antagonist is our helper."*

There is so much more to do! Thousands of aircrew, civilian and military worldwide fly overwater everyday without proper training.

Is this only Survival Systems' responsibility to change this? No!

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De la théorie à la pratique : conception d'un cours CRM pour les équipages d'hélicoptères militaires

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SUMMARY

Cockpit Resource Management (CRM) is one of the ways available to improve flight safety. "Human factors" training's are designed for military aircrews but due to the absence of international military regulation, there is a large variety of training goals and contents between countries. From the know-how acquired during the design of "Puma" helicopter CRM, guidelines can be given for "human factors" training policy definition and CRM courses design. In conclusion, data exchange between countries is proposed by the authors as a way to standardize "human factors" training in order to improve either flight safety and aircrew proficiency in multinational missions.

1. INTRODUCTION

Les formations aux facteurs humains de type "Cockpit Resource Management" ou CRM ont fait leur apparition dans l'aéronautique au début des années 80 pour améliorer la sécurité des vols. Si les principes du CRM sont toujours les mêmes, les concepts manipulés évoluent régulièrement. Pariès (1996) résume fort bien cette évolution en distinguant 4 générations de CRM : la première centrée sur la dynamique des petits groupes, la seconde sur une approche normative du travail en équipage, la troisième sur la gestion des capacités et limites humaines et la dernière sur l'extension du champ d'application du CRM à tous les intervenants qui sont en relation avec l'équipage. Les formations CRM des années 2000 aborderont des problématiques théoriques différentes de celles des années 80. D'un point de vue pratique, les produits de formation CRM utilisés dans les systèmes aéronautiques se situent à différents niveaux de cette évolution. L'aéronautique civile à travers l'Organisation Internationale de l'Aviation Civile (OACI), la Federal Aviation Administration (FAA) aux États-Unis et la Joint Aviation Authority (JAA) en Europe émettent des recommandations, développent des programmes de qualification (Advanced Qualification Program) et dictent des réglementations pour dresser un cadre d'élaboration, d'application et d'évaluation des formations aux facteurs humains. Au niveau militaire, l'aéronautique n'est pas régie par ce cadre. Les états-majors, soucieux d'améliorer la sécurité des vols, ont pris conscience de l'importance de la formation des équipages aux facteurs humains et ont développés de façon plus ou moins importante des cours CRM. C'est ainsi que depuis les années 90, nombre de forces aériennes de l'OTAN ont mis en place des formations aux facteurs humains. Pour cela, la méthode suivie consiste bien souvent à transposer en les adaptant au milieu militaire les principes développés en milieu civil (Prince et Salas, 1993). Il faut cependant prendre en compte 2 éléments :

- le milieu militaire à travers ses institutions, son fonctionnement et son personnel présente des spécificités qui peuvent pénaliser l'acceptation d'un produit trop proche des CRM civils.
- l'absence d'homogénéité entre les pays favorise la diversité des approches alors qu'une standardisation de la formation d'équipages amenés à travailler de plus en plus les uns auprès des autres dans les opérations multinationales, serait nécessaire.

L'aéronautique de défense française a développé en 1997 et 1998 un CRM pour hélicoptère de manœuvre Puma. L'originalité de cette approche réside dans le fait que l'hélicoptère Puma est utilisé à la fois par l'Armée de l'Air et par l'Aviation Légère de l'Armée de Terre et que les deux états-majors ont décidé d'élaborer un produit commun de formation. Le souci de répondre aux attentes des équipages et de proposer une formation CRM qui soit acceptée par tous permet de tirer des enseignements pour la conception d'un cours CRM au profit des équipages militaires. Dans cet article, les points suivants seront abordés : les spécificités militaires, les principes et la méthode d'élaboration

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d'un CRM, l'évaluation et la réglementation associée à la mise en place d'un CRM.

2. LES ENJEUX DU CRM DANS L'AÉRONAUTIQUE MILITAIRE

Depuis 1994, les forces aériennes de défense françaises se sont dotées d'un plan d'actions "facteurs humains" pour améliorer la sécurité des vols (Doireau et al., 1996). En marge d'actions pour améliorer la préparation mentale des équipages aux opérations, accroître la condition physique des personnels navigants et augmenter le retour d'expérience, le plan comporte un volet consacré à la formation des équipages aux facteurs humains. Les personnels navigants doivent développer des habiletés pour travailler en équipage de la façon la plus sûre et la plus efficace possible dans le cockpit. La connaissance par les personnels navigants des limites et capacités humaines tant au niveau individuel que collectif et dans la relation qui s'instaure au sein d'un équipage avec un système pour réaliser une mission, est au cœur de cet apprentissage. Fort de l'expérience acquise dans la mise en place de formations CRM pour les équipages d'avions de transport Transall C-160, de Boeing C-135 FR ravitailleur et de chasseurs bombardier biplace Mirage 2000 D et Mirage 2000 N, les états-majors de l'Armée de l'Air et de l'Aviation Légère de l'Armée de Terre ont décidé de mettre en place une formation CRM pour les équipages des hélicoptères de manœuvre Puma. Les enjeux associés à ce projet sont multiples.

Depuis ses débuts, l'aéronautique militaire est sensibilisée à l'importance des facteurs humains pour la sécurité des vols et a développé des enseignements aéromédicaux. Cependant, tout un volet du fonctionnement humain en situation de travail prenant ses racines dans la psychologie, la sociologie et l'ergonomie a été peu pris en compte. Son importance ne se discutant pas, les personnels navigants ont développé un savoir intuitif fondé sur l'introspection à partir de leurs propres expériences. Chacun a ainsi développé une vision personnelle des facteurs humains qui oriente l'activité dans le cockpit et les actions à mener pour améliorer la sécurité des vols. La part importante des erreurs humaines dans les accidents et incidents aériens est à l'origine de travaux scientifiques qui ont permis de développer un corps de connaissance pour modéliser l'activité des opérateurs en situation de travail. La notion d'erreur humaine et l'analyse du rôle de l'équipage pour la sécurité des systèmes (Reason, 1990) ont évolué et permis de faire des recommandations pour améliorer la formation des personnels. L'introduction par des personnels non navigants de ces concepts dans une communauté professionnelle considérant jusque-là que ces aspects relevaient de leurs seules compétences, soulèvent de leur part des questions sur la pertinence d'une telle approche. Si certains sont convaincus du bien-fondé, il faut noter que d'autres sont beaucoup plus résistants. En fait, cette résistance s'explique plus par une mauvaise représentation ou une méconnaissance de ce que sont les notions traitées par les facteurs humains que par des arguments formalisés. Toute action visant à développer l'enseignement des facteurs humains doit s'accompagner d'une information importante vis-à-vis de l'ensemble des personnels navigants aussi bien dans les unités opérationnelles qu'au niveau des différentes structures hiérarchiques. Il faut expliquer l'apport des facteurs humains par rapport aux pratiques existantes. L'enseignement des facteurs humains ne remet pas en cause les pratiques actuelles mais est une formation complémentaire qui a pour objectif d'atteindre un niveau de sécurité encore plus élevé. Il n'est pas la solution à tous les problèmes mais une voie constructive pour mieux les appréhender et trouver des solutions. L'enseignement n'apportera pas une suite de recettes "miracles" qui supprimeront les événements aériens mais des connaissances qui doivent permettre aux équipages de développer des habiletés plus sûres dans le cockpit. Cela requiert un investissement de la part des personnels afin qu'ils prennent en compte leurs propres attitudes pour les faire évoluer. On passe d'une démarche "passive" de la sécurité dictée par des règlements à des niveaux hiérarchiques supérieurs, à une démarche active et constructive au niveau de chaque individu. C'est en ce sens que l'enseignement des facteurs humains peut constituer les bases d'une culture ou d'un esprit "sécurité des vols".

Pour être acceptée, la formation se doit de répondre aux attentes des équipages. Cet enjeu, bien qu'évident, mérite d'être développé sous deux aspects :

- le développement d'habiletés spécifiques au travail en équipage nécessite de prendre en compte les caractéristiques de la situation de travail. Si les connaissances fondamentales liées au travail dans le cockpit présentent un degré de généralité qui les rendent valides d'une situation aéronautique à une autre, il est cependant essentiel de les particulariser à l'aéronef et aux missions des équipages qui suivent la formation CRM. Cela signifie qu'il est difficile de transposer tel quel un CRM existant et conçu pour les équipages d'un aéronef à des équipages d'un autre aéronef. L'intéressement des personnels et la crédibilité des messages transmis requièrent d'aborder les préoccupations aéronautiques quotidiennes des équipages. Les personnels navigants doivent se reconnaître dans le contenu de la formation, tant dans les thèmes abordés que dans les recommandations, le choix des exemples ou les situations aéronautiques évoquées ;

- au-delà du contenu, la forme du produit de formation est importante. Les facteurs humains sont souvent abordés dans les unités opérationnelles à travers des actions "sécurité des vols" ou sous forme de conférences de sensibilisation. En instaurant un produit de formation identifié comme tel, et en lui donnant une forme qui ne porte à aucune critique (esthétique des cours, qualité des supports, professionnalisme des formateurs et qualité de l'accueil des stagiaires), on démontre l'importance de cette formation et l'engagement de la hiérarchie. On donne à la formation un statut à part entière tout comme pour les autres formations. L'acceptation n'en est alors qu'accrue de la part des équipages.

La formation aux facteurs humains n'est pas une entité indépendante, isolée des formes classiques d'entraînement des équipages (OACI, 1989). Elle doit s'étendre progressivement à toutes les formations techniques afin de mieux intégrer les habiletés non techniques dans l'activité quotidienne aéronautique. Ce point est important car il faut bien comprendre et bien faire comprendre au commandement que la mise en place d'une formation CRM n'est pas un acte isolé, se suffisant en lui-même. D'une part, le succès de l'enseignement des facteurs humains passe par son intégration dans la formation technique, seule garantie d'un apprentissage et d'une application des habiletés non techniques. D'autre part, il existe une demande de la part des équipages opérationnels ayant suivi une première formation initiale, pour que la formation facteurs humains ne se limite pas à des stages mais s'étende à l'ensemble des activités d'entraînement (Grau et Valot, 1997).

Contrairement à l'aéronautique civile, l'aéronautique militaire ne dispose pas au niveau international de recommandations sur l'implantation de cours CRM. Une telle absence peut avoir plusieurs conséquences dont il faut prendre garde :

- une absence de cadre de référence qui oblige à faire appel à des spécialistes "facteurs humains" sous peine de biaiser les objectifs de formation, ou de ne pas obtenir l'acceptation des équipages pour ne pas avoir pris en compte un certain nombre d'éléments ;
- le risque de transposer des principes de l'aviation civile sans avoir mesuré les particularités de l'aéronautique militaire ;
- une adhésion relative de certains personnels à ces formations car elles sont vécues comme pouvant remettre en cause les principes existants ou certains principes militaires. Cela sous-entend qu'une bonne information doit être diffusée préventivement et qu'il faut donner précocement un cadre réglementaire.

Le dernier enjeu et non des moindres est celui d'un CRM hélicoptère Puma commun à l'Armée de l'Air et à l'Aviation Légère de l'Armée de Terre. Cette décision a été prise dans le but d'optimiser les ressources disponibles pour la conception du produit de formation. L'objectif de départ était d'étudier la faisabilité d'un produit commun car les aéronefs sont similaires et les missions sont proches. La difficulté de cette approche réside dans les différences de culture entre les deux armes tant au niveau de l'emploi des personnels que des méthodes de travail, ce qui avait conduit à émettre l'hypothèse d'une partie commune aux deux armes et de parties spécifiques à chacune. L'étude menée lors de la conception du produit de formation pour identifier les besoins des équipages et les thèmes à traiter dans le CRM a permis d'aboutir à un produit unique qui satisfasse les équipages.

3. DÉFINITION ET CONCEPTION DU CRM

3.1. Responsabilité du produit de formation

Les formations facteurs humains s'adressent aux équipages opérationnels et relèvent de la responsabilité de l'état-major. Une formation performante et adaptée est le fruit d'un travail synergique entre personnes de compétences différentes dans les domaines du milieu aéronautique visé, de la formation, des facteurs humains et de la sécurité des vols. Le responsable de la définition et de la conception de la formation est un représentant de l'état-major qui présente une expérience et une crédibilité opérationnelle tout en incarnant les valeurs développées à travers le CRM (Byrnes et Balck, 1993). Il est important que ce responsable soit respecté par la population navigante à laquelle s'adresse la formation pour accroître la crédibilité des actions engagées. Les CRM développés dans l'aéronautique militaire française ont été gérés par le bureau sécurité des vols de l'état-major. Il apparaît cependant rapidement que si ce choix est judicieux pour satisfaire aux objectifs de sécurité, la mise en place et le suivi de la politique de formation des personnels relèvent des responsables de l'instruction. L'implication des responsables de l'instruction dès les phases initiales du projet est importante pour deux raisons :

- envisager de façon précoce les ressources et les moyens suffisants pour permettre le bon déroulement de la formation ;

- prendre en compte l'intégration et la complémentarité de la formation CRM par rapport à la formation aux habiletés techniques.

Pour ces raisons, le CRM hélicoptère a été placé sous la responsabilité du bureau sécurité des vols pour le contenu et les objectifs de formation, et sous celle de l'instruction pour son intégration dans la formation des équipages.

3.2. Le groupe de travail

3.2.1. La première tâche du responsable est de constituer un groupe de travail en charge de la définition et de la conception du CRM. Les différentes positions impliquées au sein de l'organisation aéronautique doivent être présentes ainsi que des représentants ayant une compétence dans le domaine du CRM. Pour le CRM hélicoptère, le groupe de travail était constitué de :

- représentants du bureau sécurité des vol de l'état-major ;
- représentants de la sécurité des vols dans les unités opérationnelles ;
- représentants de l'instruction de l'état-major ;
- représentants de l'instruction dans les unités opérationnelles ;
- équipages opérationnels, et
- spécialistes "facteurs humains" de l'Institut de Médecine Aérospatiale du Service de Santé des Armées (IMASSA) ayant une compétence dans les facteurs humains en aéronautique.

Au sein du groupe, chacun a une tâche et des responsabilités particulières : (ii) les représentants de l'état-major sont en charge de s'assurer de l'atteinte des objectifs et du respect de la philosophie du produit par rapport aux doctrines du système aéronautique, (ii) les représentants des unités sont en charge de la faisabilité par rapport aux ressources disponibles, (iii) les équipages opérationnels apportent leur expérience dans la définition des thèmes et pour favoriser l'acceptation du produit final par la population navigante et (iv) les spécialistes "facteurs humains" apportent leurs compétences théoriques en facteurs humains et en pédagogie.

Si chaque membre du groupe a une responsabilité spécifique, le produit final est la résultante du travail collectif et à ce titre appartient à tous les membres du groupe. Pour le CRM Puma, le groupe de travail était composé de 20 personnes dont 12 opérationnels (un équipage se traduisant pour les hélicoptères Puma par un pilote commandant de bord, un pilote, un mécanicien navigant dans le cockpit et un mécanicien navigant en soute).

3.2.2. La première tâche du groupe est de définir les objectifs de la formation et d'établir le planning de conception. A cette fin, il est nécessaire de mener des actions dans deux directions :

- d'une part, créer un espace de réflexion commun en faisant partager ses connaissances aux autre membres du groupe. Cela peut prendre la forme d'exposés, de visites, de visionnage de matériel audiovisuel ou d'étude de documentation qui permettent de mieux appréhender les domaines et contraintes de chacun.
- d'autre part, prendre connaissance de ce qui se fait dans le domaine de la formation CRM au sein de l'aéronautique militaire et de l'aéronautique civile.

Une fois cette réflexion menée, il est alors possible de définir les produits de formation destinés aux personnels d'hélicoptères. La formation s'effectuera à deux niveaux : en école de formation pour les élèves du personnel navigant et en unité opérationnelle.

La formation en école a pour objectif une prise de conscience de l'importance des facteurs humains dans l'activité aéronautique et l'acquisition de connaissances élémentaires sur les facteurs humains. Elle est dispensée sous forme d'enseignement magistral par les médecins navigants et les officiers sécurité des vols autour des thèmes classiques des facteurs humains (10 heures pour aborder les thèmes relatifs à la synergie, aux communications, aux capacités et limites du traitement de l'information, à la prise de décision, à la vigilance, au stress et à l'erreur humaine).

La formation en unité a un objectif pratique et s'adresse à des équipages opérationnels. Elle traite les thèmes "facteurs humains" dans le cadre spécifique de l'aéronef et de ses missions. Pour que cette formation puisse bénéficier au mieux aux stagiaires, il est nécessaire qu'ils remplissent les conditions suivantes : (i) avoir une connaissance théorique des principaux thèmes facteurs humains et (ii) avoir une expérience du travail en équipage suffisante pour prendre conscience de ses propres attitudes et les faire évoluer. La formule retenue pour cet enseignement est celle d'un stage de 2 jours animé par des faciliteurs et basé sur l'interactivité entre les stagiaires et entre les stagiaires et les faciliteurs. Pour accroître la richesse des échanges, les stagiaires seront en nombre limité (de 8 à 12) et représenteront les différentes spécialités professionnelles présentes dans l'équipage. Le principe pédagogique est l'apprentissage expérientiel : mécanisme par lequel des connaissances sont créées à partir d'une transformation de l'expérience (Landry, 1991). L'acquisition des habiletés s'effectue à travers un processus qui comporte 5 étapes (Lane et Korb, 1993) :

- une phase de stimulation qui permet d'introduire un thème CRM ;

- une phase d'expérience qui permet aux stagiaires de réagir et d'illustrer par leur expérience le thème traité ;
- une phase de traitement collectif qui permet de dégager des recommandations admises par tous ;
- une phase de généralisation qui permet d'énoncer des règles de comportement permettant aux stagiaires de comparer leurs attitudes aux attitudes reconnues comme les plus professionnelles afin d'acquérir les habiletés non techniques satisfaisantes ;
- une phase d'application qui permet de s'assurer de l'acquisition des habiletés non techniques.

La phase d'application nécessite des moyens en simulation ou lors de vol réel qui ne peuvent être disponibles dans le cadre du CRM qui est mis en place pour les hélicoptères. Cette phase fera secondairement l'objet d'une étude spécifique après un bilan des résultats de la première phase. Cette étude sera conduite parallèlement avec la question du renforcement des habiletés conformément aux travaux de Gregorich (1993) qui montrent que les habiletés non techniques s'estompent dans le temps et qu'elles requièrent des renforcements réguliers.

Les faciliteurs sont des personnels navigants des escadrons. Leur choix est important car les faciliteurs doivent être crédibles au regard des messages CRM. Le choix de personnels navigants est guidé par la nécessité de développer un produit de formation enseigné par des personnels navigants pour des personnels navigants, et d'atteindre un niveau performant d'interaction avec les stagiaires.

Dans le cadre du CRM hélicoptère, la phase de stimulation sera faite par l'analyse de situations vécues ou de petits films vidéo qui présentent en 3 minutes une phase d'activité illustrant le thème CRM à analyser.

A l'issue de la définition des différents produits de formation et des grandes lignes pédagogiques, le groupe de travail établit un planning qui regroupe les phase suivantes :

- identification des thèmes traités lors de la formation en unité ;
- définition du contenu et de la forme du cours ;
- conception du cours et réalisation d'une première maquette ;
- évaluation et validation de la maquette ;
- élaboration du produit final ;
- formation des faciliteurs.

En raison de la disponibilité des membres du groupe de travail, il faut une année pour réaliser un cours CRM entre la première réunion du groupe de travail et la formation des faciliteurs. Une fréquence d'une réunion par mois est retenue pour juger de l'évolution du travail et éviter les dérives.

3.3. L'élaboration du cours CRM pour hélicoptère

3.3.1. Identification des thèmes CRM

L'identification des thèmes CRM est une phase délicate car elle va conditionner la pertinence de la formation. Diverses techniques peuvent être utilisées pour identifier les thèmes du CRM. Trois sont apparues intéressantes dans le cadre du projet CRM hélicoptère :

- réflexion au sein du groupe de travail sur la base des avis des équipages opérationnels et des officiers sécurité des vols ;
- analyse des événements aériens impliquant des hélicoptères Puma ;
- entretiens dans différents escadrons auprès de personnels navigants de qualifications et d'expériences différentes. Ces entretiens sont menés par les spécialistes "facteurs humains", ce qui leur permet d'avoir un point de vue extérieur et objectif. Ces entretiens sont très importants car ils permettent de dresser une "carte" de la vie à l'escadron et dans les cockpits. Ils soulèvent des thèmes auxquels les personnels navigants expérimentés du groupe de travail n'ont pas toujours pensé car ne se situant pas dans leurs préoccupations d'experts. Les entretiens sont aussi très riches en exemples réels qui, utilisés à bon escient permettront d'ancrer la formation dans la réalité pour accroître sa pertinence et son acceptation.

Pour le CRM "hélicoptère", 30 entretiens semi-directifs d'une heure et demi ont été conduits dans l'Armée de l'Air et dans l'Aviation Légère de l'Armée de Terre auprès de pilotes "commandant de bord", de pilotes et de mécaniciens navigants d'expérience aéronautique faible, moyenne et élevée. Ces entretiens ont fait l'objet d'une analyse de contenu, qui après confrontation avec les résultats des 2 autres techniques, ont permis de valider 9 thèmes CRM. Ces thèmes étaient communs à l'Armée de l'Air et à l'Aviation Légère de l'Armée de Terre. Des différences sont apparues cependant dans la façon dont les thèmes devraient être traités en fonction de pratiques et de cultures différentes. Plutôt que de développer des produits de formation spécifiques, il a été décidé d'adapter les points particuliers à chaque armée et de sensibiliser les faciliteurs aux développements spécifiques qu'ils devraient faire à partir d'un support générique.

3.3.2. Contenu du cours

Reprenant les décisions retenues précédemment, le cours se compose de la manière suivante :

Première demi-journée :

- Introduction : présentation du cours et des règles de fonctionnement de la formation ;

- Thème "synergie dans le cockpit" : bases de la synergie, rôles et fonctions de chaque membre d'équipage, types de cockpit, particularités des équipages militaires (statut des personnels, profils de qualification, culture "mono-pilote" sur d'autres hélicoptères) ;
- Thème "de la communication au dialogue" : modèle de communication, langage opératif et langue anglaise, le mécanicien en soute lors des treuillages en SAMAR de nuit, importance des briefings et débriefings.

Deuxième demi-journée :

- Thème "prise de décision" : bases du fonctionnement cognitif, conscience de la situation et prise de décision, prise de décision collective, biais à la prise de décision induits par la nature des missions militaires ;
- Thème "gestion des tâches" : charge de travail, gestion prescrite / gestion réelle, doute et confiance, automatisation des cockpits ;
- Thème "vol sous jumelles de vision nocturne" : contraintes de pilotage, gestion des ressources de l'équipage, pièges rencontrés dans les missions ;
- Thème "erreur humaine" : mécanismes et facteurs d'erreur, gestion de l'erreur, erreur individuelle, collective et systémique.

Troisième demi-journée :

- Thème "polyvalence des missions" : missions de service, vols d'entraînement, vols opérationnels, expérience, expertise, instruction ;
- Thème "vols opérationnels" : statut des vols, autonomie des équipages, petits groupes, contexte international, stress ;
- Thème "fatigue, vigilance" : rythme veille-sommeil, performance, gestion de la fatigue.

Quatrième demi-journée :

- Études d'événements aériens. Les stagiaires se scindent en petits groupes de 3 ou 4 et analysent sous contrôle des faciliteurs, des événements aériens de Puma. Le but est de retrouver les concepts appris dans les 3 demi-journées précédentes. Chaque groupe présente ensuite son analyse aux autre participants.
- Conclusion du stage. Apports du CRM. Comment mettre en pratique le CRM ?

Pour chaque thème, il existe au moins un film vidéo pour illustrer le thème. Onze films vidéo ont été réalisés pour le CRM Puma. Les films vidéo ont été réalisés par les équipages opérationnels. Le support du cours, composé principalement de transparents, a été élaboré par les spécialistes "facteurs humains". Pour chaque thème, des guides destinés aux faciliteurs leur permettent de gérer au mieux les interactions avec les stagiaires. Des fiches "cultures" sont aussi disponibles pour parfaire les connaissances des faciliteurs afin qu'ils puissent répondre aux questions les plus diverses des stagiaires.

3.3.4. Maquette et validation du cours

Les différents éléments du produit de formation ont été évalués et approuvés par les membres du groupe de travail au fur et à mesure de leur élaboration. Une première maquette du CRM a été testée auprès d'un groupe de personnels navigants non impliqués dans la conception du CRM. Le rôle des faciliteurs était joué par les spécialistes "facteurs humains". Suite aux critiques formulées, le produit final a été validé par le groupe de travail.

3.3.5. Formation des faciliteurs

Cette étape est essentielle car elle va conditionner la qualité et l'acceptation de la formation auprès des stagiaires. Pour accroître la pertinence de la formation, les faciliteurs sont des personnels navigants des unités opérationnelles. Une première expérience faite il y a 5 ans au sein de l'Armée de l'Air, avec des personnels navigants retraités pour enseigner les facteurs humains, avait eu un impact modéré. Le manque de connaissances sur les pratiques en cours dans les escadrons par les formateurs était la principale barrière à des échanges fructueux. Il en avait été déduit que seuls des personnels navigants en activité pouvaient faire correctement ce lien entre des concepts théoriques et la réalité aéronautique quotidienne.

Le choix de personnels navigants comme faciliteurs n'est cependant pas une tâche aisée au regard de leur connaissances initiales en facteurs humains et des objectifs pédagogiques qu'on leur assigne. Ils doivent devenir des enseignants dans une discipline où à l'origine, ils ne possèdent pas de connaissances théoriques stables. A cette fin, il faut bien intégrer cette contrainte dans leur programme de formation et leur fournir tous les outils qui pourront leur faciliter la tâche. C'est pour cela qu'un guide formateur et des fiches "culture" ont été conçus.

Le choix des faciliteurs parmi la population navigante est important et doit répondre à plusieurs critères :

- les faciliteurs appartiennent aux différentes spécialités qui composent l'équipage. Il y a 2 faciliteurs de spécialités différentes pour chaque stage de formation ;
- les faciliteurs sont des volontaires et sont motivés par l'enseignement des facteurs humains ;
- les faciliteurs incarnent les valeurs enseignées dans le CRM et sont reconnus au sein des escadrons pour leurs qualités professionnelles.

La formation des faciliteurs s'effectuent en plusieurs étapes. Ils suivent d'abord un stage CRM comme stagiaire, puis un second comme observateur. Parallèlement, ils prennent connaissance des documents à l'usage des faciliteurs et apprennent les

notions théoriques. Ils suivent ensuite un stage d'une semaine à l'IMASSA où une formation pédagogique avec mise en situation est réalisée. Une fois certifié "faciliteur", ils effectuent leur premier stage en double avec un faciliteur expérimenté.
Cette formation est "lourde" et requiert de la part des faciliteurs un investissement non négligeable. En conséquence, la reconnaissance d'un statut "faciliteur CRM" est importante.

3.3.6. Évolution de la formation

Les formations CRM sont des formations pratiques qui doivent être adaptées aux réalités aéronautiques quotidiennes. Pour cela, leur contenu et leur forme doivent être examinés régulièrement à partir des réactions des stagiaires et des faciliteurs. Une réunion annuelle de synthèse sous la tutelle du responsable de la formation facteurs humains de l'état-major permet de faire le point, de définir les nouveaux axes (changement du contenu, utilisation de la simulation, etc.) et de répartir les tâches pour faire évoluer la formation.

4 EVALUATION

Dès la conception des formations facteurs humains, il est important d'envisager des outils d'évaluation de l'impact du CRM sur les habiletés des équipages. Ces outils doivent permettre de juger de l'intérêt du CRM, d'identifier les barrières aux changements d'attitudes et d'évaluer le contenu de la formation. Dans la phase consécutive à la mise en place des formations facteurs humains, il est difficile d'avoir des retours objectifs sur les taux d'événements aériens. On est obligé d'avoir recours à des indices indirects de sécurité dont on fait l'hypothèse qu'ils sont favorables à une amélioration de la sécurité des vols. La littérature propose différents indices ainsi que les méthodes pour les évaluer :

- les mesures de changements d'attitudes par questionnaire à la fin de la session ou à distance de la session (Helmreich, 1984) ;
- l'acquisition et l'utilisation des habiletés non techniques en situation par observation directe ;
- l'évolution du retour d'expérience dans les escadrons que ce soit d'un point de vue qualitatif et quantitatif.

Pour le CRM Puma, une enquête par questionnaire sera conduite au bout d'un an de pratique CRM auprès des personnels ayant suivi la formation. Des questionnaires plus systématiques exigeraient des moyens d'analyse dont on ne dispose pas. L'évaluation des habiletés non techniques est la méthode la plus pertinente mais elle nécessite de disposer d'évaluateurs compétents et suffisamment nombreux pour évaluer tous les équipages. Par ailleurs, cette méthode exige soit des moyens en simulation dont on ne dispose pas, soit d'intégrer l'évaluation aux évaluations techniques ce qui ne peut être admis en l'état actuel tant que l'impact du CRM ne sera pas démontré et son acceptation totalement acquise. Par contre, il est beaucoup plus facile de relever au sein des escadrons une évolution de l'état d'esprit des personnels navigants envers la sécurité des vols et de sensibiliser les officiers sécurité des vols au collationnement systématique des retours d'expérience. La mise en place d'outils systématiques comme des bases de données ou des fiches de recueil d'événements est un bon moyen de quantifier ces évolutions.

5. RÉGLEMENTATION CRM

Si la réussite du CRM est associée à la qualité technique du produit de formation, sa mise en place doit être régie par un cadre réglementaire qui va aider à son implantation. Ce cadre définit la politique de formation aux facteurs humains, l'organisation de l'enseignement, le statut des faciliteurs et les modalités d'évolution de la formation. L'objectif de la réglementation est de formaliser et d'institutionnaliser les formations facteurs humains pour lutter contre les barrières qui peuvent s'élever. Parmi les barrières les plus importantes, on peut citer :

- une sous-évaluation des implications de la mise en place d'une formation facteurs humains sur la formation non technique des personnels navigants ;
- l'adhésion modérée des niveaux hiérarchiques intermédiaires car la formation facteurs humains est une charge supplémentaire à gérer sans qu'elle ait été compensée dans la plupart des cas par la suppression d'une autre charge ;
- la méconnaissance et la méfiance suscitées par quelque chose de nouveau. A cette fin, le CRM est une formation obligatoire mais sans sanction. C'est un produit de formation et non d'évaluation des compétences des équipages. Le contrat pédagogique doit être clairement établi entre les stagiaires, les faciliteurs et l'encadrement ;
- attention à l'effet "lune de miel" suscité par toute nouveauté attrayante. C'est dans le long terme que le CRM aura un impact sur la sécurité des vols et la performance des équipages ;
- la phase d'installation d'un CRM est une phase délicate car toute la population navigante n'est pas encore formée. Il se crée des disparités entre équipages qui pénalisent l'évolution des attitudes et l'acquisition des habiletés non techniques ;
- éviter les dérives sur la nature des messages enseignés dans les formations facteurs humains. Pour cela, l'IMASSA est responsable du contenu scientifique des formations ;
- les faciliteurs doivent être rattachés dans les escadrons aux chaînes hiérarchiques de la sécurité des vols et de l'instruction ;

- ne pas décevoir les stagiaires car il apparaît après les premières formations, un désir d'aller plus loin dans les facteurs humains. Les responsables des formations facteurs humains doivent prendre en compte suffisamment tôt cette évolution pour faire des propositions et envisager les ressources suffisantes.

6. CONCLUSION

Les formations aux facteurs humains participent à l'amélioration de la sécurité des vols. Pour cela, elles doivent répondre de façon très précise aux questions que se posent les équipages militaires. A travers l'expérience acquise dans la réalisation d'une formation CRM pour hélicoptère de manœuvre "Puma" au sein de l'Armée de l'Air et de l'Aviation Légère de l'Armée de Terre, il est possible de faire des recommandations pour prendre en compte les caractéristiques de l'aéronautique militaire dans la conception et la mise en place d'un CRM. L'acceptation d'un CRM dépend de sa qualité "technique" mais aussi de la politique de formation qui l'accompagne. Rapidement, le CRM dépasse le cadre du seul enseignement "facteurs humains" et s'étend à l'ensemble de la formation du personnel navigant contribuant par là même à l'instauration d'une culture "sécurité des vols". L'originalité du CRM Puma était de faire un produit commun à deux organisations militaires différentes effectuant des missions proches. La méthode développée montre qu'il est possible d'élaborer un tel produit en prenant en compte les réalités de la vie quotidienne aéronautique. Les échanges dans le domaine militaire sur l'enseignement des facteurs humains en aéronautique sont peu développés. Il serait intéressant de partager les expériences respectives de chaque pays pour définir des principes de formation standardisés qui garantissent à des équipages intervenant dans des opérations multinationales, des niveaux de formation aux facteurs humains identiques.

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A Systems Approach to Selection and Training of Aircrew to the Air Ambulance Service

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1. Summary

Emergency Medical Services are recognized world wide for its highly qualified personnel, well known for their dedication and motivation to the service. Even so, regulatory practice in Air Ambulance Services varies from country to country offering different solutions to the issues of crew composition and qualification in order to ensure safe and efficient operations.

The definition of crew and issues of selection and training from a systems perspective, involves in-depth discussions on the relative impact of regulatory, as well as organizational practises. One argues the need for greater regulatory commitment in developing criteria for selection and training of aircrew to the service. In addition, one suggests that in order to arrive at well documented criteria in which all can agree, it is considered vital to involve *all* parts of the system in this process. Secondly, the question is raised whether one should be limited to a dedicated service for primary and secondary aeromedical transportation or whether one should allow for other non-medical transport missions as well. The choice of operational model will have obvious consequenses for the crew concept chosen. The role of new technology in increasing safety in the Air Ambulance Service is included in the discussion, particularly in relation to choice of operational model, choice of crew composition as well as in relation to crew training requirements.

2. Introduction

An ambulance helicopter crash in late 1996, involving the death of 4 crewmembers, started a heated discussion in Norway regarding the future organization of the Air Ambulance Service in Norway. This accident was the last in a series of accidents in the last 10 years, resulting in questions being asked as to the value of a service that was not meant to take lives, but to save them. The service's reputation as an efficient, life saving unit and a vital provider of patient treatment in a sparsely populated country such as Norway, was challenged. Looking at the accident investigation reports following the crashes, nothing appeared to be wrong technically with the aircraft. Instead of technical failure, the cause factor *human factors*, was posited as the main contributor to the crashes seeming to point an accusing finger at the pilots. When the familiar solution "technical failure", that is easily identified and possible to quantify, couldn't be applied, a detailed investigation was undertaken to analyse the accident thoroughly, examining all possible aspects. An officially appointed working group was also formed and mandated to provide answers to the many questions that rose after the last tragic crash in 1996. This paper will seek to address the major issues discussed. A brief retrospective glance will reveal that the foundation of today's problems may lie in the present organizational structure of the official air ambulance service in Norway. Based on this, we will show how it relates to the problems encountered on selection and training criteria for the crew involved and also show how these problems might have contributed to the tragic accidents Norway has experienced in the last decade.

2.1 The birth of an Air Ambulance Service in Norway

The first air ambulance transports in Norway started already in the 1920s. They were run by private companies in cooperation with The Red Cross Foundation seeking to serve a large part of the country. After World War II, the RNoAF also played an active part in ambulance transportation, which by then was becoming an increasingly important provider of patient care. Given Norway's vast area, sparsely populated districts and difficult topological and climatic conditions, the air ambulance service proved the most effective form of patient transportation, and often the only one available. Despite the lack of a formal organization, the service continued to grow, allowing several informal practises to emerge. Idealism and initiative seemed to be the guiding lights and the service experienced regular critical evaluations from the government. It seemed difficult, however, to come up with a reasonable governmentally run alternative on which all could agree.

Further attempts to formalize an officially run air ambulance service were initiated in the 1970s. Lengthy discussions, however, on which department should be in charge slowed the process down considerably. During this period a privately owned and run emergency medical service using helicopters emerged, manned with a crew composed of pilots, anesthesiologists, and

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dedicated rescuemen trained as nurses. Inspired both by the Swiss/REGA and the German/ADAC model, this service represented an alternative.

Given the obvious lack of consensus in the organizational model, it wasn't until the late 1980s that the formal establishment of a governmentally run air ambulance service took place. At this time there where several actors on the scene, all actively participating in the discussion on how to run a successful service most effectively. Debates ran high on issues such as organizational model, operational concept and last but not least crew composition. Several voices raised the issue of the increasing risk of loss of life due to the lack of a standard operating procedure for the crew involved.

2.2 The accidents

- A medical doctor was killed when he was struck by rotating helicopter rotor blades. The helicopter was landed on a slope and the doctor was unaware of the proximity of the rotor to the slope. This accident posed questions concerning selection and training of medical participants in the service to meet the demands of the operations.
- While flying a mission carrying a seriously ill patient, who also happened to be the relative of an influential person in Norway (!), the helicopter hit power lines in attempting to avoid thick fog. The rescueman seated next to the pilot, was responsible for providing nagivational aid to the pilot while airborn, but at the time of the accident was seated facing backwards assisting the doctor. This accident raised the obvious question of pressures placed on crew to continue a flight despite marginal operational weather conditions, as well as the issue of crew composition and tasks allocation.
- An EMS helicopter hit power lines on a night mission. Although the formal report is not yet released, the main issues discussed involve once again that of crew composition and training as well as a discussion of the need for navigational aids such as moving maps and night vision goggles (NVG).

What do these accidents tell us ? Individually, they each raise questions concerning the role of the crew concept in an operational setting. Technically there was nothing wrong with these aircraft. However, pointing an accusing finger at the crew alone will not solve the problem. In order to get the full picture, it is important to look behind the immediate scene of the accidents and reflect on the roles of the responsible parties involved as well as the governmental policy that applies.

Summing up these accidents we wish to focus on 3 relevant issues in the further discussion : a) governmental/organisational policy, b) choice of operational model, and c) crew selection and training.

3. Governmental policies for the Air Ambulance Service in Norway

Establishing a new organization means agreeing on a set of premises that apply for the whole operational concept, addressing issues such as political, philosophical and practical implications for an air ambulance service. Ideally, the discussion should start at the overall organization of a service by developing a formal policy as a basis for both operation and crew concept in Norway. Non-profit organizations, however, are usually run by highly motivated and idealistic people, and the determining premises have often been established in an *ad-hoc* manner. The ad-hoc method seems to have been the predominant problem-solving strategy used in this case, often based on individual interests and tradition, rather than on a systematic approach, agreed on by all involved.

Part of the explanation for the ad hoc approach in Norway is political. Governmental responsibility for the operation of the air ambulance service is shared between two separate departments. The Department of Transportation sets the rules for all operational issues, including those for the pilots and rescuemen, while the Department of Health is responsible for all medical issues such as requirements for medical crew formal qualifications, training and economy. These two departments are both responsible for running the service, but have not made an effort to communicate or coordinate their practices. In organizations where the responsibility is divided between two or more departments, one often sees a reluctance in decision making, which leaves the entire organizational concept developmentally inhibited. An example of this is the problem encountered in Norway in the past years, of agreeing on a common governmental policy for the air ambulance service. Lacking a standard policy, it has been up to the individual operator to establish a policy suitable to its own specific operational needs. These safety standards are often a result of the operators own interests and based mainly on financial concerns.

4. The choice of operational model

Since the Norwegian government has not been able to establish an air ambulance service, several private operators have stepped in to fill the gap. However, in order to remain in business it has been necessary for some companies to fly other missions than strictly ambulance related missions. An important issue in today's discussion on a future air ambulance service, is whether the service should concentrate exclusively on patient handling, or whether there should be room for other types of transport missions as well. There are, of course, good arguments for both alternatives. It is important to note, however, that the choice of an operational concept will have a definite impact on the choice of crew concept, crew scheduling, aircraft type, equipment as well as the actual location of bases.

Flying different types of missions means performing different tasks, which may require different crew constellations. A potential problem may arise due to this change in constellation : Medical crew assigned to air ambulance missions are often given additional tasks during a mission, for example providing an extra pair of eyes in assisting the pilot in avoiding high terrain while searching for landing sites. This provides the pilot with valuable assistance, on which he might become accustomed to depend. This extra pair of eyes is not available during other transport missions where medical assistance is not required, a factor which presents a potential decrease in situational awareness as well as a potential increase in workload for the pilot when he needs it least. In addition, different missions will require different equipment and/or different aircraft types. Having to relate to two different aircraft types during a work period as well as considering different equipment needs, we are introduced to obvious possibilities for human error, especially in periods with high workload. The tendency to confuse procedures and basic handling of the aircraft illustrates vividly why these issues must be addressed carefully before arriving at a chosen concept.

5. Crew concepts - selection and training

One might ask why it is necessary to discuss organizational policies and operational concepts in order to address the issue of which persons are considered crew members in the Norwegian air ambulance service. In accordance with a systems approach, the choice of crew is influenced by an array of factors, including the aviation industry's standards, governmental rules and regulations, choice of operational concept, availability of technical expertise and financial support possibilities. In order to arrive at a common standard for crew composition to meet the demands of the air ambulance service, one has to take all these factors into consideration. There will always be ongoing discussions as to who is considered the right-stuff pilot, rescueman, doctor, nurse or technician. Furthermore, there will also be ongoing suggestions for the right crew composition that can meet the requirements of a given mission. But in Norway there is no consensus so far and there is ample room for different interpretations due to the lack of formal guidelines. However, throughout aviation history there have been common areas of concern that have provided a certain structure, namely those of selection and training.

5.1 Selection of personell to highly specialized operations

Referring to the accidents mentioned earlier, a common topic of concern deals with the issue of selection of personell for a highly specialized service. Selection of operational crew will always result in heated discussions that reek of subjectivity and self-interest. Obviously a discussion on personell selection must first address the question of who is considered to be a crew member. The Joint Aviation Authorities (JAA) propose in their regulations on crew concepts for the Helicopter Emergency Medical Service (HEMS) that the medical expertise in the HEMS systems are to be classified as " medical passengers ". There has been uncertainty in the field concerning the implications of this proposition. Joint Aviation Requirements (JAR) terminology states that "this medical passenger shall receive a briefing as detailed in paragraph [..]". In short, this briefing includes familiarization with aircraft, entry and exit under normal and emergency conditions, use of medical equipment required for the mission and the use of intercom systems in the aircraft. Joint training with the rest of the crew is not considered. Several question arise in this context :

- What does the term medical passenger imply ?
- How much and what type of training is necessary for this category when they merely function as passengers when airborn ?
- How is the term " passenger " interpreted by the medical expertise ?
- What possible consequences might be incurred when part of the group on board is defined merely as being passengers during part of the mission instead of as crew ?

Our main concern with these questions is the possible consequence to safety as a result of excluding part of the group from being team-members. Crew Resource Management training (CRM) offered to the military and civilian aviation system in Norway is developed and implemented partly to highlight and encourage teamwork and the importance of being an active part of a crew. An important issue taught in CRM training is the benefit of crew situational awareness when all members of a group work as a team, and where the philosophy is that all human resources are considered vital to increase safety. The fact that CRM training in some of the companies involved is only offered on a regular basis for the pilots says it all. One might even postulate that until the entire aviation industry accepts and actually practices CRM, changing our well known abbreviation from crew resource management to company resource management, a policy change from medical passenger to crew, with its implications for selection and training, will prove hard to attain. Meanwhile, recommendations have been proposed by the first appointed working group in Norway on HEMS safety, suggesting a specific Norwegian policy that ascertains that medical personnel be accepted as fully integrated crewmembers.

Apart from defining the formalities around crew concepts, it is also important to set a standard for all aircrew involved, a standard that all operators will abide by and that will take into consideration the special demands that are placed on these operations. Selection of all crew members for this specific job has only recently been an issue in Norway. Standards do exist on pilot selection in JAR as is also true for the category HEMS crew member. Although national policies on selection include general criteria for all categories, the criteria do not take into consideration how the demands of flying in the air ambulance service differ from other professions' demands. One example that illustrates the need for specific selection requirements for crew in the service was encountered only recently. When hiring personell for a new air ambulance base in Norway recently, this lack of specific medical and psychological selection criteria for the medical passenger category resulted in a situation where several of the medical doctor applicants had identified medical conditions such as epilepsy, heart disease and anxiety problems ! It is obvious that these candidates might easily end up not only as *passengers* onboard, but possibly joining in as patients as well ! A selection process that includes not only formal professional qualifications to prove professional competence, but specific medical and psychological criteria as well is viewed as a vital step towards safe operations.

The discussion on crew concept in the cockpit, both in terms of crew qualifications and crew composition, is an equally important issue to address . Following the tragic accidents where aircraft hit power lines, there have been heated discussions both in the media and in the aviation community at large on the number of pilots required in the cockpit to increase safety. According to JAR, a two-pilot system is called for in certain conditions, such as during night operations and over unfamiliar terrain. In addition, JAR suggests a second crew category in the cockpit, termed HEMS crew member. This category, given specific training listed in the regulations, may replace the pilot in the lefthand seat. Rather than based on emotionality and founded on a nice-to-have basis as is the observed tendency, crew composition in the cockpit must be viewed in relation to existing regulations, the type of missions to be flown, geographical considerations, as well as on well documented criteria for crew qualifications and job descriptions in both seats up front.

5.2 Work scheduling

A related problem in discussing crew concepts, focuses on the issue of work scheduling. As the system functions today, medical personell have their primary job at the nearby hospital, sharing their shifts at the air ambulance service with several colleagues. For some of the operational concepts, this implies a change in crew composition every 1-2 days for the crew involved, the same pilot and rescueman, but different doctors. The argument for this solution has been to ensure medical updating, but from a flight safety point of view, one might point out the negative effect this has on situational awareness and teamwork according to good CRM. Having to adjust to new crew members several times during a shift, often implies taking the time to "break in" the new crewmember. It is common knowledge that ensuring team functionality implies developing a mutual trust among the team members as well as taking time to get to know the other crewmembers abilities, personality and idiosyncrasies ! A study conducted in 1986 by Clay Foushee and his colleagues on flight crew fatigue and its impact on human error, illustrates this point. Foushee found that crews going off duty performed more efficiently and with fewer errors when fatigued compared to crews going on duty. Foushee also stated in this study that one should be aware of the danger of too much familiarisation leading to complacency, which is considered to be a problem area for crews who fly together on a long term basis. For the crew in the air ambulance service, however, long term does not extend over more than one week. Besides, there is definitely nothing monotonous in air ambulance service missions ! A point confirmed in a study conducted by Barker and his colleagues. Barker states that as the mission increases in complexity, it will take longer for the crew to reach their peak performance. Elaborating on the importance of crew familiarity, and its relation to mission complexity, these findings lend further support to the importance of coordinating work schedules to increase teamwork. A suggestion has been proposed to reduce the total amount of doctors assigned to the service in order to increase their familiarity with fellow crewmembers. While still maintaining medical proficiency through their primary job at the nearby hospital, the chosen doctors for the service then have a greater chance at becoming an integrated part of the team.

Furthermore, and adding on to the discussion on different work-schedules for the crew, there is the issue of fatigue. Dividing work-schedules between duties at the hospital and stand-by duties at the air ambulance service during a one week shift period, introduces a definite potential for fatigue related errors. The effect of fatigue on performance is well known and serious consideration must be taken to construct shift-schedules for the crew in the air ambulance service that ensures the need for professional updating on one side without jeopardising good teamwork and safe operations on the other. Designing work schedules must in any case involve the active participation of professionals who are familiar with fatigue issues, and must not be left entirely to the different operators, as has been the case so far.

6. Conclusion

The air ambulance service represents the most accident prone of all operations in Norwegian commercial aviation. The risks involved in the service are plentifold and complex. Based on the accidents suffered since its start in the 1920s, there are several areas of concern,

areas that have been proposed as vital for further development and imperative for safe operations.
Still, the discussion on crew concept and composition is going on as one is looking at formal and standardized criteria on background, selection, education and training of the entire crew. These are all important aspects in developing a high quality alternative to ground ambulance transportation. Before reaching for solutions to these aspects, an agreement on the underlying premises for a service must be reached, answering the important questions of who is responsible for quality control of the system, thereby providing the service with a much needed transparent system within which all operational issues are decided. Hopefully, working through a structured system like this, agreed upon by all involved, the aim of reaching greater consensus will be achieved. At the same time, such a system will increase the probability for developing a service that is founded on a well documented and safety-focused basis.
Ad-hoc solutions can only be compared to what we in medical terms consider symptoms treatment - it will give temporary relief, but it will not provide long-term healing of the system as a whole, and that is what we are aiming at.

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Primary and Secondary Air Medical Transport in Ambulance Helicopters

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THE CHALLENGE

In all imaginable situations going along with medical emergencies, time is the crucial determinant which can make the difference between life and death.

In medicine it is a well proved axiom that one can influence and improve the prognosis of casualties once qualified medical support has been initiated (15). To shorten the interval for wounded soldiers or patients in lack of adequate therapy, emergency medicine seeked the advantages of helicopters to provide medical care at the earliest possible time and to guarantee a very effective and rapid response to life-threatening situations (21).

Air rescue medicine has developed extensively over the past 60 years and is still changing. The increasing engineering progress in aviation and the current state-of-the-art medical equipment opened the way for helicopters and fixed wing aircraft to perform as modern, highly mobile intensive care centers (10).

The air ambulance service represents a complex, demanding and responsible working place for aircrews and specialized medical personnel.

Therefore, professional expertise and procedures are mandatory to understand and carry out critical care interventions in the **Air Medical Transport (AMT)** environment.

Experienced and well trained personnel and the optimized preparation of the patient before take-off ensure effective medical care in flight even over long distances (7, 22).

MEDICAL PRINCIPLES

General

The task of the rescue service is to ensure that the population is provided with demand-adjusted and proficient services of emergency rescue and patient transport.

This is implemented predominantly by the ground rescue service, including treatment by emergency doctors. The air rescue service acts as a supplement to the ground rescue service.

Therefore, air rescue principally has to cover the same range of services as ground rescue. In the area of emergency rescue (primary treatment), air rescue has to take over with priority the treatment by emergency doctors, if that cannot be performed by ground rescue within the given maximum permissible response time. This applies in areas where infrastructure related to emergency doctor service is insufficient (in the mountains, over the sea, in large wooded areas, etc.).

Definition:

Aeromedical rescue/evacuation is defined as the movement of casualties by air transportation under medical supervision to and between medical treatment facilities.

The special tasks for Air Rescue / Ambulance Helicopters are as follows:

- fast and direct transport of medical specialists and equipment to the disaster site
- direct and careful transport of emergency patients to more distant specialized hospitals with maximum individual care
- carrying out urgent secondary AMT of intensive care patients (IC patients) between hospitals
- SAR missions (ICAO, IMO)

There are two principal rules in aeromedical evacuation.

- The decision to evacuate a patient by air necessitates experienced aeromedical judgement after adequate examination and best-available therapy. The thorough assessment of the medical benefits for the patient versus the hazards which might occur in the air.
- On the other hand, there are no absolute medical contra-indications for AMT. Accepting only stable patients is not a golden rule, because stabilization on the emergency site is not always practicable (stabilized versus stable patients).

SOME STATISTICS

In 1997, 50 air rescue helicopters were in action in 57 728 missions over German territory (failure rate 7 691 = 13%). A total of 50 977 patients were treated and, 21 035 primary AMT and 5 716 secondary AMT missions took place.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

The military part in the German air rescue system is considerable. Eigtheen military helicopters of the Bell UH-1D type (German Air Force) and six Sea King MK 41 (German Navy) are integrated in the system. They are divided among 11 SAR detachments according to the tasks of ICAO/IMO and 9 rescue centers to support the civilian **Air Medical Transport Service (AMTS).**

Efficiency of Aircraft Ambulance Rescue Missions in Germany (1997)

	total	military
Missions	57 728	11 343
Failure rate	7 691 (13%)	2 242 (17%)
Treated Patients	50 977	9 921
Primary AMT	21 035	3 246
Secondary AMT	5 716	1 427
Pure SAR Missions		444

In 1997, the German military SAR service responded to 13 585 alerts (failure rate: 2 242 = 17%), flew 11 343 missions equivalent to 5 933 flying hours, treated 9 921 patients and transported 4 673 persons.

Dealing with pure SAR missions, only 444 alerts were documented (13).

PRIMARY AIR MEDICAL TRANSPORT (AIR RESCUE)

The rapid and direct air transport of medical specialists and equipment to the disaster site and the direct and careful medically monitored transport of stabilized patients to further specialized medical care can be defined as primary AMT.

A perfect example was given when the helicopter response was demonstrated effectively on the occassion of the horrendous ICE railroad accident which occured in Germany in June 1998 when 34 rescue helicopters were involved.

The most disastrous Railroad Accident in German Train History (27)

Chronology and Results
Wednesday June 3rd, 1998

- **10.59 Accident of the ICE 884 „Wilhelm Conrad Röntgen“ in Eschede**
- **11.05 to 11.35 Alerting Phase**
- **13.15 End of Evacuation of all critically injured cases**
- **100 fatalities; 101 persons injured, 59 in critical conditiions**
- **Evacuation from theatre to 22 hospitals**
- **1200 rescue personnel, 45 physicians**
- **34 helicopters in theatre (20 from German Federal Armed Forces, 14 from civil rescue oganisations)**

The medical indication for rapid AMT often results in using different types of trauma scores (NACA Index; Glasgow Coma Scale; Trauma Score (TS); Injury Severity Score (ISS); APACHE-II; RAPS, TISS).

However, the indication to move emergency patients by air is given in polytraumatic patients with:

- severe fractures
- spine injuries (paraplegia)
- thorax trauma (instability, respiratory insufficiency)
- open injuries of different body regions
- skull fractures (cranio-cerebral trauma - CCT)
- extreme loss of blood

In the field of Internal Medicine, the following diagnosis can be considered for primary AMT:

- MCI (cardiogenic shock; cardiac rhythm disturbances)
- pulmonary embolism
- acute cardiac insufficiency
- respiratory insufficiency
- bleedings
- comas (metabolism)
- intoxications

Some explaining studies/experiences

In 5 123 primary AMT missions (mission failure rate 16.3 %) by the German air rescue helicopter Christoph 41 during the period from 1987 to 1992, a total of 4 285 patients received first medical treatment and 2 098 (48.75 %) were transported by air.

It could be demonstrated that, by means of frequent intubation and administering large intravenous volumes, polytraumatic patients could be treated rapidly and effectively. A good level of preclinic stabilization was proved by the high rate of successful primary missions and the low rate of early lethality (3).

In 1992, a total of 656 children, fallen ill or injured, were transported by REGA in Switzerland. These were 415 primary and 241 secondary AMT missions. While 73 % of the sick children were in a life-threatening condition, this was only the case with 44 % of the children injured (NACA Index > III) (17).

During the time period from 1990 to 1995, a total of 1 408 patients were treated by the emergency doctors of rescue helicopter Christoph 4, which had already received first treatment by doctors available at the emergency site (14). It became evident that in 51.3 % (n = 723/1 408) of the cases further medical treatment was performed. These measures were required in 86.2 % of the cases if transport was done by helicopter, but only in 27.7 % of the cases if it was ground transport.

The share of invasive measures was remarkably high:

- thorax drainage 6.6 %
- intubation and
  inducing of narcosis 18.3 %

The early intubation in the preclinic polytrauma management is an essential measure for patient stabilisation.

Indication for early intubation in preclinic polytrauma management (24)

- **traumatic resuscitation and persistent hypovolemic (hemorrhagic) shock**
- **unconsciousness with severe CCT**
- **acute obstruction of the upper airways**
- **sustained respiratory insufficiency**
- **polytraumatic patients (danger of MOF)**
  - **thorax trauma**
  - **trauma combination**
  - **pattern of injury**
  - **polytraumatic score (NACA, Glasgow)**

In his norwegian study, HOTVEDT et al. (9) however demonstrated that only 41 emergency patients (e.g. 11% of the total of n = 370 evacuated by the rescue helicopter between Jan 1, 1989 to Dec 31, 1990 at the university hospital of Tromsø) were considered in a specialist assessment to have gained additional medical benefit from AMT compared to that achievable by ground ambulance support. The main reason was that helicopter transport did not offer any advantage in treatment that could not have been given otherwise.

SECONDARY AIR MEDICAL TRANSPORT (INTER-FACILITY TRANSFER)

Secondary AMT may become necessary in the case of serious illness and/or injuries after stabilization, but also if complications develop that cannot be dealt with in hospitals and which require further treatment by specialized medical centers.

Those helicopters in use carry medical equipment for complete invasive and non-invasive monitoring, artificial respiration using all possible ventilation patterns, and facilities for electric therapy and pharmaco therapy (1).

However, when circumstances do not permit air transfer of trauma patients from community hospitals to a trauma center, ground transport appears to be as safe as air transport over distances ranging from 10 - 130 miles (23; 26).

Therefore, a center of coordination between air rescue and ground rescue, not only from the cost benefit aspect, is strongly recommended.

Due to field related specialization of medical centers in our nations, the aeromedical Inter-Facility Transfer of critically ill and/or injured patients over long distances has gained more and more importance.

SEARCH AND RESCUE

Challenges and difficulties concerning the primary AMT management of emergency patients in mountainous or maritime locations are often caused by delayed and insufficient alert, exposing the casualties to the cold and extremely hazardous environment.

Only by helicopter, effective preclinic treatment is available. Patient rescue is more than often carried out by hoist maneuvers in adverse weather operations and under extreme psycho-physiological workload (5; 11; 19; 20).

International organizations (ICAO, IMO etc.) have been formed to standardize SAR operations requiring international cooperation. The member nations provide internationally agreed comprehensive standards, practices and procedures for SAR within their territory over land and sea. Helicopters are effective tools because of their low speed and hovering capability. They are usually equipped with a hoisting device for rescue and delivery operations.

SAFETY ASPECTS

Air medical rotor-wing aircraft have an alarming history of accidents, which result in morbidity and mortality all over the world.

In 1986, 14 emergency medical service helicopter crashes occurred, destroying or substantially damaging 9 % of the US air medical helicopter fleet (8).

During air rescue missions, 10 German military SAR helicopters crashed between 1989 and 1995, causing eight fatalities and 18 injured (12).

It is an undoubted fact that flying of air rescue helicopters includes a series of possible stressors, both physical and psychomental, and requires a lot of skills and experience from the total aircrew team performance (6).

On the other hand, safety issues in aero-medevac equipment get more and more into focus. Electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) of medical equipment used on board must be evaluated to avoid effects on engine control, communications and navigation of the aircraft and on the mode of operation of the equipment itself. Other safety issues to take into account for specialized aeromedical equipment include susceptibility to g forces, rapid deceleration and acceleration.

The same is true for the influence of human factors, vibrations, altitude and electric safety on the mode of operation of the medical instruments. All of those have an effect on the safety of the patient, the flight platform and crew.

Therefore, the establishment of internationally agreed definitions of both technical and medical standards, with particular consideration being given to the concept of „safety first", is mandatory (4).

C 4 I

The medical C 4 I rescue organization must be capable of planning, executing, controlling, supporting and auditing the full spectrum of aeromedical support functions.

It must be capable of providing and ensuring a seamless system of control of treatment, evacuation and transfer of information, including patient documentation from the initial point of injury or sickness throughout the evacuation chain to definitive treatment. This improves productivity and gurantees better management of operation's cost and quality of care.

Telemedicine, once the technology is fully developed, will have an enormous impact on helicopter AMT operations by strengthening the AMT crew's future ability to provide the right level of rescue and care to a patient. Helicopters can thus be diverted to more deserving or urgent cases, making operations more cost effective and reducing asset redundancy (25).

DISCUSSION AND PROSPECTS

AMT is a citical component of an integrated health care system. The use of helicopters to transport patients is becoming the standard of care for critically ill and injured persons requiring transportation to distant specialized medical centers (2, 16, 18).

However, many questions remain unanswered regarding

- the use of AMT versus ground rescue/transport,
- the appropriate utilization and integration of AMT into the care and rescue management strategies,
- financial and clinical outcome analysis,
- increased AMT productivity at reduced operating costs (cost- effectiveness),
- standardized C 4 I and medical equipment assets,
- level of proficiency training and experience along with standardized procedures,
- patient classification,
- civilian-military cooperation and coordination in air rescue operations.

Medical literature and statistics stressing which patients would derive benefits from AMT are limited and/or not always precise in their scientific formulation of problem questions.

The development of a valid applicable scientific model for air medical operations is one of the major challenges in our days. Such a model must be able to define the prerequisites and needs to analyze the performance and appropriateness of air medical services. Therefore, stored and available data must be evaluated for statistical analysis, quality assessment, documentation, administration, research and training programs.

The importance of well-defined aeromedical terms, parameters and procedures, including an approved international medical scoring system are essential to guarantee a cost effective and medically successful AMT.

A cornerstone in the future success of air medical programs is the evidence of specific health care regimes exclusively qualified for airmedical transport.

Facing the current dramatic change in our nations' health care and funding systems, the financial and clinical outcome analysis is critical to the continued survival of our Air Medical Transport Services.

CONCLUSION

To sum it up, medical rescue and evacuation would be unthinkable without qualified **primary** and **secondary AMT**, which proves the success of its human life-saving role on a daily basis all over the world, when medical emergencies occur. However, there is a need for objective standards and criteria in the civilian-military **AMTS**, which may only be achieved after additional and extensive patient outcome studies (prospectively and retrospectively), in addition to cost-benefit analysis.

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Current Operational Issues in the Civil Guard Air Service

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SUMMARY.

The aim of this paper is to present a short description of the Helicopter Units of the Civil Guard. Beginning with a description of the general tasks of the Civil Guard, its organization and statute of its personal. Later on, a superficial approach to the Helicopter Units within the Civil Guard is exposed. In this paragraph, I will discus some aspects such as the organization, the territorial deployment, the aircraft models that it fly, the missions that it fulfilled, and finally a study of the operational problems that often appear in the such missions development.

1. INTRODUCTION. THE SPANISH CIVIL GUARD

The Civil Guard is an institution, which has just completed 150 years. The Spanish Civil Guard is a military-based Armed Institute that belongs to the state law enforcement, explicitly entrusted by the Constitution, always depending on the Central Government. It depends on the Internal Affairs Ministry (Home Office) in all those issues concerning the services related to public security and other domains dictated by Law, as well as on payments, posts, quartering and material. Nevertheless, it depends on the Minister of Defence about the promotions and personnel status (on service duty...), as well as on those military missions they are entrusted with. In wartime and during the state of siege, the Civil Guard will exclusively depend on this Ministry. Finally, the Civil Guard depends on both Ministries about the selection, training, improvement, armament and territorial deployment.

We are more than 70.000 members all around Spain and other countries.

Just like other state law enforcement its responsibility is to ensure freedom and individual rights established by the Constitution, and to provide for the citizens' security, with the following tasks:

To monitor the observance of laws and general provisions by carrying out the orders it may receive from the competent authorities.

To assist and protect people and assure the conservation and custody of assets in jeopardy for whatever reason.

To keep watch over and preserve public buildings and facilities when necessary.

To protect and escort V.I.P.´s

To keep and, if needed, restore public order and safety. To investigate crimes to uncover and arrest alleged criminals

To gather, receive and analyse any data relevant to public order and safety. To cooperate with Civil Protection Services in situations of high risk, catastrophes or public disasters.

The Civil Guard has, the sole jurisdiction over the following tasks:

Those due to the current legislation on weapons and explosives.

Safeguard against tax fraud and activities aimed at the avoidance and pursuit of smuggling.

Traffic, transit and transport surveillance in inter-city public roads.

Custody of overland communication routes shores, borders, ports and airports and centers and facilities, when needed due to its importance.

Watch over the observance of provisions concerning nature and environmental conservation, hydraulic resources, as well as fauna, fishery, flora and any other issue related to nature.

Inter-city transportation of prisoners and people under arrest.

1.1. ORGANIZATION

The Civil Guard Headquarters, organ of the Internal Affairs Ministry and integrated in the State Security Secretariat, is composed of the following Units with rank of General Sub-department:

a. Operative Subdepartment
b. Staff Subdepartment
c. Supporting Subdepartment

Attached to the Headquarters is the Superior Board of the Civil Guard, consulting organ formed by all the Generals on service duty of the Civil Guard.

The Major General, Head of the Operative Subdepartment, commands the Zones and the following Units:

- Reserve and Special Units Command
- Intelligence and Information Command

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

- Traffic Grouping of the Civil Guard

The Major General, Head of the Staff Subdepartment, commands the following units:

- Staff Section
- Training Central Command

Below the Major General, Head of the Supporting Subdepartment, is the Supporting Command.

The Traffic Grouping and the above mentioned Commands are commanded by High Ranking Officers.

1.2. TERRITORIAL DISTRIBUTION

The peripheral distribution is composed of Zones, Commander's Headquarters, Companies, and Posts. The Traffic Grouping has its own peripheral distribution.

Each Zone comprises Autonomous Community, being its headquarters in: Madrid, Toledo, Mérida, Sevilla, Murcia, Valencia, Barcelona, Zaragoza, Pamplona, Logroño, Vitoria, Valladolid, Santander, Oviedo, Santiago de Compostela, Santa Cruz de Tenerife y Palma de Mallorca. The zones are under the command of a High Ranking Officer or Colonel of the Civil Guard.

The Commander's Headquarter, under the command of a Colonel or a Lieutenant Colonel, comprises a whole province or the towns of Ceuta and Melilla. Each Commander's Headquarter is divided in several Companies and these are divided in Posts.

2. THE CIVIL GUARD AIR SERVICE. -

In 1972, the Civil Guard purchases two helicopters BO-105. It was begun the Helicopters Group. Today, we have a fleet of 26 helicopters (BO-105 and BK-117), and 60 pilots.

Last year, the new Basic Organizational Structure of the Internal Affairs Ministry determined the functions of the organs of the Civil Guard Headquarters. It has caused the introduction of Fixed Wing Units, and it has given to Air Service a new responsibility, the airports and aeronautical facilities security.

In this way, the Civil Guard Air Service has two general tasks. First of all, organising, operating and maintaining the Civil Guard aeroplanes and helicopters, increasing the operative capacity of the Territorial Units, as well as doing independent actions when the other Units can't do them. In second place, it has the responsibility of the co-ordination and technical support of the Spanish Airport security Units.

The Civil Guard Air Service fulfils a great variety of missions in all the national territory like the following ones:

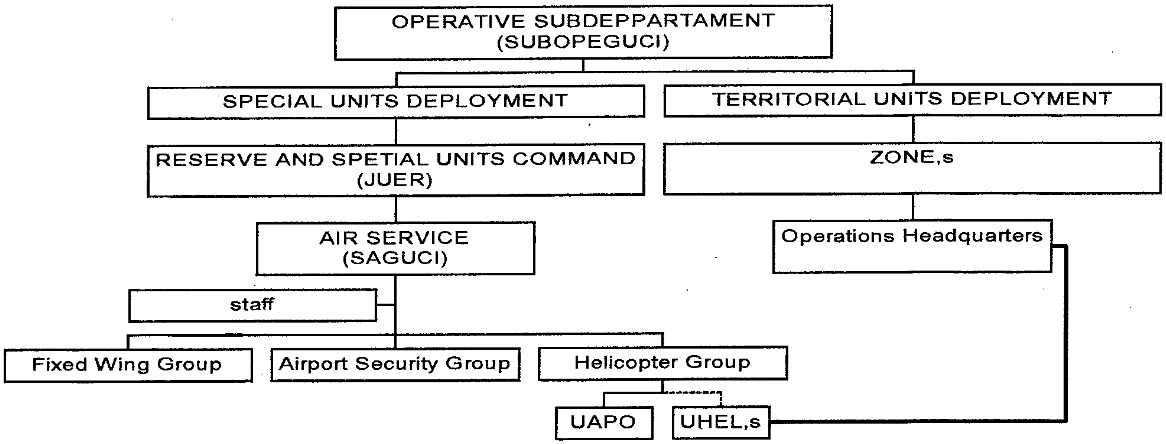
- High Mountain rescues.
- Other Units or organizations support.
- Medical evacuations.
- Air patrol in the struggle against the smuggling, the drug dealing and the illegal immigration.
- Providing citizens' security and public order.
- In a first phase, technical and doctrinal direction of the Airport Security Units.
- Providing technical advice to the Civil Aviation Authorities in those missions of aeronautical administrative policeman assigned to the Civil Guard.

2.1. ORGANIZATION:

The Air Service of the Civil Guard (SAGUCI), with dependence of the General Operations Subbureau, is commanded by a Colonel with a large experience in flight. It is articulated in:

- Command.
- Staff.
- Helicopter Units.
- Fixed Wing units.
- Airport Security Units.

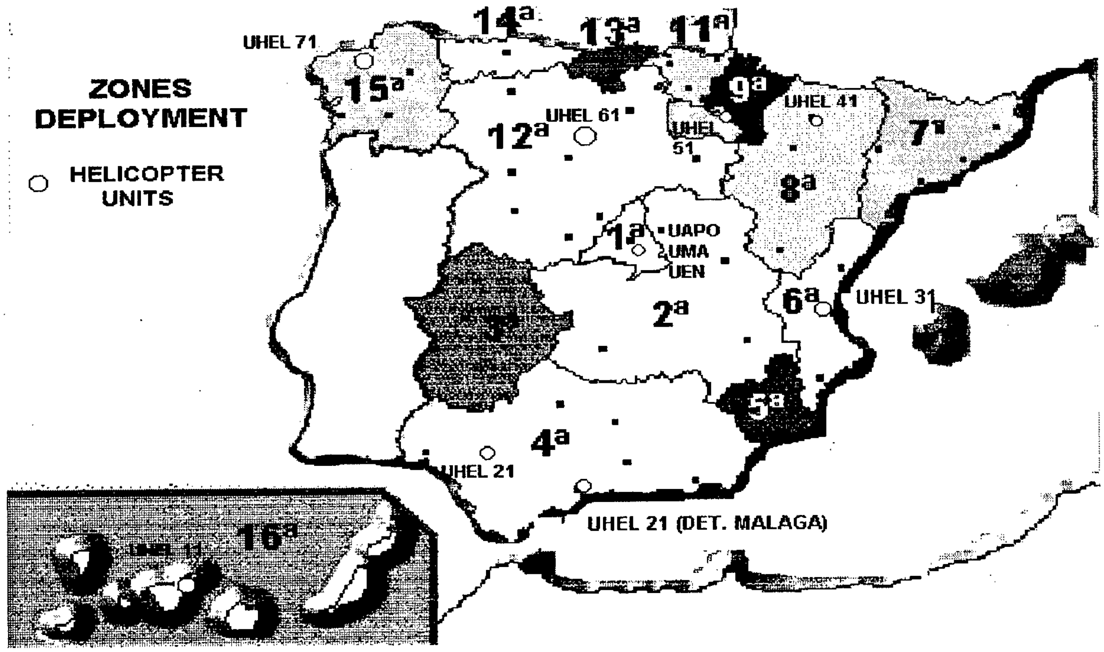
CIVIL GUARD AIR SERVICE ORGANIZATION CHART



3. THE HELICOPTER UNITS. -

3.1. ORGANIZATION:

The Units of Helicopters (UHEL) are special small units that the Zones count with to support by air the execution of the missions commended to the Civil Guard by the Law.



These Units of Helicopters organization is based on a double dependence. The tactical control belongs to the General in command of the Zone where the Unit is located, while the control in the technical aspect corresponds to the Air Service Colonel, through the Helicopters Group Command.

The UHEL is functionally articulated as follows:

Command. - A Lieutenant Colonel or Major with a large experience in flight is in command. He depends directly on the General of the Zone, through the Zone Operations Headquarters.

Staff. It is formed for the office personnel and supporting vehicle drivers.

Operations and Maintenance. – The Second in command is an Officer who fulfils these missions, and he also is the crews appointment responsible. He programs and he supervises the execution of the instruction and training plans too. Likewise, he is answerable to the UHEL Command for the supervision of the maintenance works over the assigned helicopters.

Information. - A pilot with rank of Sergeant does this job. He updates all the aeronautical information and operative data for the missions planning.

Safety of Flight. - An Official, if it is possible Flight Safety graduated, carries out this function. He makes the opportune reports to the UHEL Command about if the levels of risk in each moment are within allowed limits.

The UHELs have a variable number of personnel, depending on the missions to develop and their responsibility area. For example, in the Valencia based Unit (UHEL-31), the team is composed of 7 pilots and 4 mechanics.

3.2. TASKS

The missions that statistically suppose most of the activity of the Units of helicopters of the Civil Guard are the following ones:

To provide security. - Protection of the free exercise of the rights and the citizens' freedoms, and criminals' persecution once made the crime. These missions are carried out through air patrol of surveillance, togheter with personnel from the territorial Units.

Fight against terrorism. - Transport of special Intelligence and Anti-terrorist Intervention Units, as well as the control and pursuit of vehicles and suspicious people of belonging to terrorist groups.

Mountain and high mountain search and rescue. - These missions are carried out in intimate collaboration with the Mountain Intervention Groups of the Civil Guard. Their members are real specialists in escalade and rescue. Often, these works consist on winch rescues or injured people's evacuations in not accessible places by other means.

Searching for people in the rural areas. - In this case, the helicopters collaborate with work that Territorial Units carry out by ground. The Helicopter usually rakes hard access areas .

Searching for ships over the sea. - In these missions the proceedings are co-ordinated with the ships of the

Civil Guard's Marine Service. Usually, they consist on looking for crafts with problems or shipwrecked in the vicinities of the coast (12 Miles or less)

Coast Guard, in collaboration with the Civil Guard's Marine Service and the Customs Service, preventing and repressing smuggling operations, the drug traffic and the illegal immigration.

Nature protection. - Nowadays, this is one of the most important mission. This kind of work is carried out flying accompanied of experts in these issues regulations. During the mission, they try to discover not authorised contamination disposal, taking photographs and samples of the possible infractions in order to serve as evidences.

To escort and to protect personalities.- It is part of the established missions during national and international authorities official trips.

Mobile Post of command. Usually, it takes place during public disturbs, illegal strikes, and similar situations in order to co-ordinate several Civil Guard's services or units.

3.3. TERRITORIAL DISTRIBUTION

The criterion in which the current distribution is based is the Territorial Units of the Civil Guard air support. The biggest effectiveness has been looked for, locating Units where the problems exist although they are not in the centre of its action area.

Every Unit develops all missions assigned to the Civil Guard Air Service, although each one of them carry out an specific kind of mission due to the peculiarity of their action area.

The Units of Helicopters and their location are the following ones:

UAPO. -(Supporting Unit) Torrejón Air Base. Madrid
UHEL 11. - Los Rodeos Airport. Tenerife (Canary Islands)
UHEL 21. - Sevilla Helicopter Bases. Sevilla.
UHEL 21.- Detachment of Málaga. Málaga Air Base. Málaga
UHEL 31. - Manises Air Base. Valencia
UHEL 41. - Monflorite aerodrome. Huesca
UHEL 51. - Logroño Helicopter Base. The Rioja
UHEL 61. - León Air Base. León.
UHEL 71. - A Coruña Airport. A Coruña
UEN. - Training unit. Torrejón Air Base
UMA. - Maintenance Unit. - Torrejón Air Base

3.4. CREW

All the personnel of the Air Service belong to the Civil Guard.

The standard crew consists of two pilots and one mechanic, although it can vary in according to the mission. In this way, to carry out a winch rescue, two pilots make up the crew, one of them to the controls and the other one as rescue winch and radio operator.

In night surveillance missions, working with FLIR, the crew consists of two IFR trained pilots and one mechanic operating the FLIR camera.

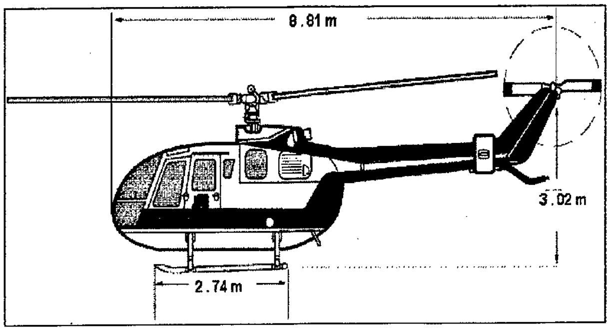
Nowadays, the pilots' training level is high, however there are some problems for the new pilots training due to budgetary reasons.

The qualification is obtained by means of the Military Helicopter Pilot Course and the Instrumental Flight Course. They are developed in the Spanish Air force Helicopter Training Centre in Armilla (Granada).The formation is completed with own training courses in the Training Unit (UEN) in Torrejon Air Base (Madrid) and then with the Units instruction plans. Likewise, we are present in some improvement courses such as Flight Safety Course, Helicopter Test Pilot Course, and others. Maintenance Pilot Course, for example, is received in the Spanish Army Training Centre.

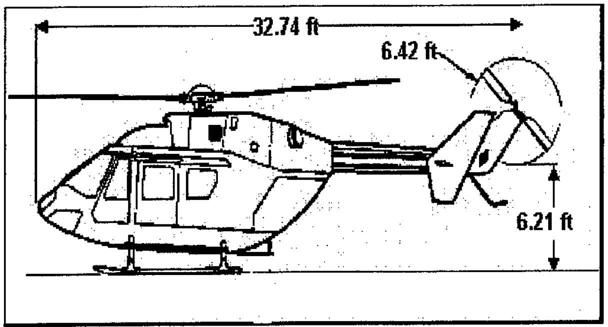
3.5. HELICOPTERS

a) Models.- For these missions execution, the Civil Guard has a fleet of 26 helicopters consisting of:

- 18 BO 105 (CB-CBS)
- 8 BK 117 (A3-B1)



It is expected that in a few months, three helicopters, model Augusta A109, property of the Ministry of Fishing will be operated by the Civil Guard Air Service Helicopter Units in order to the fishing surveillance.



b) Helicopter equipment. - An standard equipment configuration does not exist. Each UHEL is provided with adapted helicopters to its specific work. The usual configuration, for example, in the UHEL 21 (Seville - Málaga) is a BK 117-B-1 with IFR flight certification, equipped with integrated GPS search radar, emergency floats, FLIR, search light and rescue winch. This helicopter has the specific mission of persecution of the smuggling and the illegal immigration. These missions are usually carried out co-ordinated the Civil Guard's Marine Service and the Service of Custom.

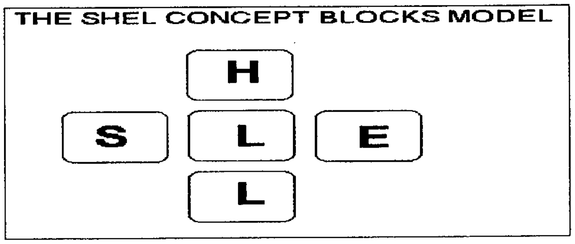
However the UHEL 41 (Huesca) helicopters, are usually devoted to mountain search and rescue. Due to this circumstance, they use BO-105 CB or CBS, in VFR version, fitted with rescue winch.

3.6. OPERATIONAL ISSUES.-

Often, during a mission execution, some difficulties are added to the mission specific ones. The pilots comment those difficulties in the daily briefings or through the incident reports. When these problems repeatedly appear, in all the missions or in a certain mission type, we are in front of that we denominate an operational problem.

First of all, let us shortly remember the SHEL concept, just as Frank H.Hawkins[1] describes it, since following this concept I have approached this topic.

The original SHEL concept is named after the initial letters of its components: Software, Hardware, Environment and Liveware. Hawkins uses a "building block" model to explain and to develop these concepts.


THE SHEL CONCEPT BLOCKS MODEL

In the centre of the model is man, or the Liveware.

The first of the components, which requires matching with the characteristics of man, is the Hardware; it is the Liveware-Hardware interface.

The second interface is that between the Liveware and the Software or non-physical aspects of the system such as procedures, manual layout, and others.

Next in the model is the Liveware-Environment interface, to adapt the environment to match human requirements.

The last interface is between people. It is the Liveware-Liveware interface.

a) Liveware. -Pilots.

The Civil Guard's pilot could be described as a male, from 24 to 45 years old, married, with medium or superior university degree. The military rank of most of them is from Sergeant to Captain. Generally, they are enough motivated by their work and they do not usually originate discipline problems.

Main operational problems that have been observed related with this concept are the following ones:

- Some Units have long periods of personnel deficiency due to in the new pilots qualification courses scarcity.
- Excess of callow members in some Units. This circumstance originates work overload in the most expert personnel or a significant increase in the accident risk level.

b) Hardware.-Helicopters.

The main problems originated from the helicopters design are:

BO 105

- Fatigue and back pain due to the in flight posture. These problems appear after approximately two flight hours and then are increased progressively. In this helicopter model, the collective control lever is relatively back displaced, what originates a very uncomfortable posture in high power ranges, such as during hover operations, take off and landings. Added to that, the seats are too hard and they do not admit any vertical regulation. This problem causes a pilot concentration decrease, and sometimes a dangerous tendency appears. It is to abbreviate the procedures, jumping some step. This last phenomenon is more evident when the mission consists on a series of repetitive tasks.
- Low helicopter performance in high mountain missions (more than 5000 feet over sea level), with ambient temperature over 15° C. Under these conditions, the pilot experience in this kind of missions and the previous study of the mission conditions is of the biggest importance. An approach manoeuvre that is not carried out appropriately can originate an emergency situation, since this type of missions often is executed near to the helicopter performance limits.
- The passengers' door is too narrow to introduce a stretcher after a winch rescue and it can be a very painful, chancy and dangerous task for the winch operator.

BK 117

- Insufficient Forward visibility. In this helicopter, like in other many ones, the instrument desk limits the forward visibility. This problem has not importance when the landing point is a runway in a military Base or a helipad. But, when we must land in a not prepared point, with obstacles all around and it is necessary adjust perfectly the glide path, there is a moment, from 80 to 10 feet of high, that the pilot gets lost the landing point, just in the most delicate moment in the approach.
- When the cyclic control stick is moved toward the left, in forced positions, the stick trips with the pilot's left leg before arriving to its position limit.
- Absence of tail rotor control on hover with crosses winds from the left side at 30 knots or more, due to the vertical tail stabilizers.
- Risk of crash of the main rotor blades with the tail vertical stabilizers during the start up with lateral winds

bigger than 30 knots.

- Easiness of exceeding the mast moment during landings in inclined ground or wind at 20 or more knots.

c) Software. -Manual, procedures...

The problems that have been detected in this aspect come from the changes that often appear in the manuals and in the procedure list. When a procedure changes, it exists a period of time in which some pilots continue applying the annulled procedure. This problem is solved through instruction flights and comments in the daily briefing.

d) Environment. -

Inside this group, they could been included the following ones:

- Communications overload. - These problems, not very habitual on the other hand, usually appear when the mission takes place in the airports vicinities. In these occasions, the crew must maintain three or more channels of open communication at the same time. In this case, the pilot to the controls usually maintains the aeronautical communications and all the aspects related with flight, and the copilot the rest, included the police communications and all the related with the specific mission (pursuit of the objective, co-ordination with other flights etc.). Still with a perfect cabin understanding, in some occasions such as when a very low altitude flight is needed, which implies cables, TV antennas, buildings, etc., the crew usually have a communications saturation that, added to some characteristics of the flight, it can have safety problems as consequence.

- Reduced visibility. - The flights in bad weather are frequent, since when the accidents usually take place, people's disappearances in the mountain, etc., it is usually when worse the weather is. In these circumstances, it usually serves for little the instrumental flight, should replace these lacks with the pilot's experience, his concentration capacity, his serenity and his wisdom. Unfortunately, sometimes this is not enough and accidents take place with fatal consequences. In this question we have some experience, since two of the three accidents with mortal victims have been due to be carried out the missions under very low visibility conditions.

- Pressure. - Many of the search missions consist on the localisation of missing people or accident victims. Usually the notice to begin the search is delayed, since at the time that the family ones or friends take in notifying the disappearance it is necessary to add the time that dedicates on the part of the ground personnel to try to find that person for other means. This way, we are frequently that the notice to the Unit of Helicopters usually arrives when it hardly has left one or two hours of daylight to search. All we know that, in some cases (children or old men), to spend the night to the bleakness can suppose that this person can die. In these circumstances, the pressure of the environment (family of the missing person, journalists, etc.) it can take to the crew to assume risks above the permissible thing and the habitual repetition of these processes can give place to the stress appearance.

- Lastly we meet with the "return to home" phenomenon. It consists in that the pilots assume many more risks than during the development of the mission when they return to their base after a mission, mainly if the mission day is close to weekend.

e) Group relationship or Liveware-Liveware interface.

In connection with this interface, most of the problems have their origin in the errors in the cockpit communication. These problems are not frequent, but in some occasions they have given place to incident and even to some serious accident. Statistically, the origin of most frequent problems is in the following circumstances:

- An excessive flying experience difference between the crewmembers. Sometimes, this situation causes a disproportionate authority relationship inside the cabin, due to this circumstance the second pilot thinks that the aircraft Commandant never makes errors, for what feels unable to make any observation although he is aware that they are in a dangerous situation.

- Verbal confusions. Inadequate communication often lies at the root not only of conflict and inefficiency but also of accidents. We had an evidence of this affirmation few years ago. A Civil Guard of a Antiterrorist Special Unit died during the execution of a descent from the helicopter when one of the pilots loosed the rope due to an error in the communications with ground controller. Soon after this accident this mission type procedures were changed.

4. REFERENCES

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Operation of Helicopters During the Chernobyl Accident

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In this report I would like to discuss our experiences with the use of "small" aviation (helicopters) during the tragic events of April 1986, and during the aftermath of the accident at the Chernobyl Nuclear Power Station. In addition, I will report on the creation of the State System for the Response to Aircraft Incidents and on the use of aircraft during emergencies.

The Chernobyl catastrophe was an extraordinary event of a planetary scale. It affected the lives and activities of many millions of people, not only in Ukraine, but also in Russia and Belarus. It has resulted in substantial financial losses and has obstructed the implementation of many agricultural programs.

Although the tragic event happened twelve years ago, the problems caused by it are still with us. We are reminded of it on a daily basis by the suffering of many people and by a multitude of social problems, which add to the burden of today's conditions of our country.

It is quite impossible to overcome a catastrophe of this order with the assets of a single state. Joint actions are necessary and we wish to thank all the countries and international organizations which have been helping us.

Let me remind you of some historical events, and explain the circumstances of the accident. On 26 April 1986, at 01.23 Kyiv time, the fourth unit of the Chernobyl Nuclear Power Plant (NPP) exploded. The cooling system and the ceiling were torn apart, and radioactive masses from the reactor core were blown into the air. The roof caught fire.
For the first time in the history of mankind the dreadful force of atomic energy out of control became clearly visible. The whole of the USSR was involved in the emergency operations. The decision to use aviation was taken in the morning of 26 April.

The tasks that faced the helicopter crews were:

- air visual reconnaissance;
- air radiation reconnaissance;
- air chemical reconnaissance;
- air engineering reconnaissance;
- video-, photo- documentation and reconnaissance;
- air thermal reconnaissance;
- transport of people and cargoes;
- evacuation of sick and wounded people;
- blocking of radionuclides escaping from the damaged reactor;
- spraying special liquids over the territories with high levels of radiation;
- taking samples from soil with high levels of radiation;
- protection of the exclusion zone;
- detailed mapping of the contaminated areas around the Chernobyl NPP.

Control of the aircraft in the emergency zone was executed by the Operation Group of the Ministry of Defence. On 27 April 1986, the joint aircraft group was established. It consisted of more than 90 different types of helicopters.

Crews worked in the zone on "dirty" helicopters. Replacement was allowed after receiving 25 R. Allocation of the joined aircraft group was depended on:

- minimum range of operation;
- qualitative maintenance of helicopters;
- possibilities for rest;
- radiating safety.

Flight control of the helicopters in the region of the Chernobyl NPP was carried out via ultra short wave radio contact from an improvised flight control tower located on the roof of the "Pripyat" hotel.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

Let me detail the procedures and methods of the operations. Air visual reconnaissance was carried out with the goal to gather information about the scale of the accident, the status of the destroyed reactor and the progress of the work on the 4th unit. As a rule, Mi-8 helicopters were used for these missions, which were manned with members of the Governmental Commission, or members of the Operation Group. The results of the reconnaissance missions allowed the Governmental Commission to adjust the procedures and the management of the emergency operations in response to the accident.

Air radiation reconnaissance was carried out from the first to the last working day. The first flight of a Mi-8 helicopter for air radiation reconnaissance took place at 13.30 on 26 April 1986 (S. Volodin was the pilot). The helicopter crossed over the NPP and followed the trail of the radio-active cloud. The crew reported that the radiation level above the destroyed reactor exceeded the admissible limits of the DP-3V dosimeter (500 R/hr). Today, Col. Volodin and his crew still serve in the Ukrainian Air Force.

As a rule, air radiation reconnaissance was performed by An-24r and Su-24mr planes, and by Mi-24, Mi-8 and Mi-2 helicopters. In addition, radiation reconnaissance of areas with low radiation levels was provided by making the helicopters land at specific locations and by using special teams, equipped with DP-5V dosimeters, at a distance of 50-100 meter from the helicopter. In this way, radiation level measurement errors due to background radiation from the helicopter fuselage and engine could be avoided. This method required multiple landings (60-80 for 6-8 hours of flight) and was very demanding for crews as well as helicopters.

Special devices for air radiation reconnaissance were only installed in the Mi-24r helicopter. The crew was in a hermetically sealed cockpit that was equipped with a system of special filters and air conditioning. This type of helicopter regularly executed flights over the destroyed reactor at the minimum admissible altitude and speed, in order to measure the radiation levels at certain control points. To measure the field of radiation, seven flights had to be made over the reactor. In other aircraft, regular radiation control equipment was installed.

Air chemical reconnaissance was provided with Mi-24r helicopters and An-12 planes by taking air samples. These were delivered at airfields which were close to the laboratories. As a result of these flights, forecasts could be make concerning the movements of the radioactive dust.

Air engineering reconnaissance was provided by Mi-2, Mi-8 and Mi-26 helicopters, with the objective to determine the best evacuation routes for the population, as an aid to engineering projects in the affected zone, and to assist in the construction of roads, bridges, and ferries.

Video and photographical reconnaissance missions used different types of aircraft, but only the Mi-24r and Mi-8 helicopters, and the An-30 airplanes were specially equipped for perspective photographing. Their equipment included tools for information processing, as well as analysis.

In particular, I would like to mention the air thermal reconnaissance missions. There was a permanent need for this kind of reconnaissance. Scientists needed information about the changes in the temperature field in order to make recommendations for further work. The first thermal reconnaissance flight over the reactor was executed by M. Volkozub (pilot-inspector from Kyiv). The measurements were executed by academician Legasov, who was on board of the helicopter.

Temperature measurements were made in the following manner: under the helicopter, a steel cable of 200 meter length was suspended, with thermocouples across the length of the cable. In order to prevent the cable from swinging, leaden loads weighting 40 kg each were attached, that were 10-15 meter apart. The helicopter would hover above the reactor at an altitude of 250 meter and would insert the thermocouple into the rupture of the reactor. The measuring process took more than 8 minutes. In order to aim precisely, and to correctly carry out all the maneuvers associated with the measurement procedure, the helicopters needed two coordinators for each flight. One coordinator, on board of a Mi-26 helicopter at an altitude 200 meter, gave lateral instructions. The other gave instructions on the distance from the roof of a house in the city of Pripyat. As a result, absolutely reliable data were collected about the temperature field. Before the introduction of this procedure, the temperature field data contained many errors. Initially, the measurements were carried out on the basis of data received from satellites and from aircraft.

The Chernobyl accident did not necessitate the evacuation of the population and the station personnel from the contaminated territory with helicopters. The well-developed network of highways, the railway network and water communications enabled the swift evacuation of large numbers of people without aviation. However, a large number of aircraft was kept in readiness for evacuation purposes.

Helicopters were primarily used for the transport of personnel and assets involved in the emergency operation. When the necessity of fast delivery of large size cargoes emerged, helicopters were used. An example is the delivery of equipment for nitrogen regeneration of the Chernobyl NPP, which consisted of six units, each weighting 11-12 tons. These flights, with load cargoes attached to a rope with a length of more than 200 meter, were unique. In general, the number of transport flights exceeded 6500, whereas more than 23000 people and 5000 tons of different loads were transported.

Evacuation of the sick and wounded was provided by specialized sanitary flights when it was necessary. For this task, the helicopters were not re-equipped. As a rule, Mi-8 helicopters were used for this goal.

Crews of the Mi-26, Mi-6 and Mi-8 helicopters carried out the main body of the work on blocking the discharge of radionuclides from the damaged reactor. Such operations were carried out by helicopters for the first time in world practice. Due to the high levels of radiation, other ways of approaching the damaged reactor than from the air were not available. Initially, the operations were carried out at an altitude of 200 meter above the reactor, and the loads were delivered by dropping them by hand. This was an extremely laborious, ineffective and dangerous method. The crews could fly no more than 2-3 times before they had received the maximum radiation dose for flying crew. A much better method of blocking the radionuclide discharge from the reactor was discovered by trial-and-error. The loads that had to be dropped were suspended from an external attachment under the helicopter. The helicopter would take off and fly to the reactor at an altitude 200 meter with a speed of 100-110 km/h. The dropping of the load was controlled via commands from the operation zone. Good interaction between flying crews and flight coordinators was achieved in a very short time. About 2000 flights of this type were carried out by the helicopters. They dropped more 5000 tons of different loads. According to a Governmental Commission conclusion, 80-85% of the droppings were exactly in place. As a result of these operations, is was possible to start the emergency works on the destroyed unit from the surface on 6th of May.

In addition to these operations, aircraft were for the first time in world used for spraying special liquids on the territory, forests and roads with high radiation levels. These liquids formed a layer on the surface that prevented the spreading of radioactive dust by the wind. About 6000 of such flights were executed. The treated area encompassed 2500 hectare. This task was executed by the crews of the Mi-26, Mi-6, and Mi-8 helicopters and the An-12 airplane. Four tanks with a capacity of 14 tons were installed on the Mi-26 helicopter, while the tank on the airplane had a capacity of 15 tons. The area was sprayed from an altitude 60-70 meter with a speed of 50-60 km/hr. The strips that were sprayed had a width of 12 meter. In order to provide a layer of sufficient thickness, 20-30 flights were necessary. The An-12 airplanes proved to be ineffective for these operations, because the liquid that was sprayed from the aircraft would disperse into an aerosol and fail to create a surface layer with the necessary thickness.

It turned out to be necessary to systematically take soil samples, in the direct vicinity of the NPP, as well from different locations in the 30 km exclusion zone. For this, the Mi-24r helicopter was used, which had special equipment. Such flights allowed to collect soil samples with high radiation levels, and to supply field laboratories.

After the explosion and the fire, great amounts of radioactive mass were dispersed. Specially equipped helicopters were used to determine their exact location.

With the object to reducing the negative influences of the radiation on the organism of the crews, the Medical Service took the following prophylactic measures:

- iodine was delivered to all personal on the first working day;
- anti-radiation medicine was delivered to all crews before any flight to a zone of strong radiation;
- from the 15th of May onward, all aviation personal received drugs which improved the

resistance of the organism to adverse external environmental factors and to ionizing radiation;

- for the protection against external gamma-radiation, leaden belts were used, and cockpits were protected by leaf lead;
- vitamin-enhanced food was delivered on a daily basis;
- working hours were limited to 1,5-2 hours for engineering and technical personal of the Mi-26 helicopters;
- on the helicopters' landing zone, camps were set up with the purpose of reducing the time one had to stay in the aircraft;
- daily sanitary treatment of the personal and careful medical control.

The distribution of food was organized in a very original way — on the floor of a dining room, created in a Mi-6 helicopter. This was very rational procedure in a radiation-contaminated area. The food was brought in by the helicopter-dining-room from clean regions.

The experiences with the operation of "small" aviation in the context of the Chernobyl accident demonstrate that the state needs to have helicopter crews and units in a permanent state of readiness. Part of the forces have to be ready for immediate action (within the first hour from the onset of an emergency), and part of forces is needed for the mobilization of other forces. The forces have to be based near regions with technologically-dangerous enterprises.

In the Ukraine, we have started to re-organize, in the framework of special medicine, sanitary aviation not only as tool for the earth-air-earth transport of sick or injured people (to hospital establishments), but also as an asset for the direct delivery of special equipment and skilled medical personnel to emergency areas. Our mobile, so-called "flying hospital" has received high praise from experts. Some NATO experts have had a chance to familiarize themselves with this organization and work at a practical demonstration during the AGARD Workshop on Aeromedical Evacuation that was held in Kyiv in September 1997.

We have numerous examples of "small" aircraft, specially equipped for aeromedical evacuation and other emergency tasks; mechanical equipment, medical and other special equipment, protection devices and other assets for SAR teams and other units.

With the object to improving the organization of the protection of the population against emergencies, and guaranteeing safety and health, Ukraine has created a United Search and Rescue System of Aircraft Operations. The organization of SAR Aircraft Operations was assigned to the Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chernobyl Catastrophe.

The Main Center of Coordination of Air Search and Rescue Operations provides coordination by the state and offers a rational organization of the airmobile SAR forces and assets during emergency operations. Five regional coordinating SAR centers were created. They control SAR operations by duty forces and assets, and they also coordinate the operations of SAR region teams. All missions are carried out by "small" aircraft (helicopters).

The SAR Aircraft Operations are financed by the government of Ukraine.

British Army Helicopter Casualty Evacuations in Belize (1995-6)

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Summary

The British Army Training Support Unit Belize supports jungle training for British military sub-units, and for the Belizean Defence Force. Training is carried out at remote jungle and mountain sites. The economic infrastructure of Belize is such that few substantial roads exist. A few main routes link the handful of major population centres but even these main highways are impassable by civilian vehicles under rainy conditions. Access to rapid medical aid is also impeded by the dispersion of medical facilities.

There has been a British military presence in Belize since the 1970s, and the Government of Belize has been assisted since then by moving casualties by air when necessary. After the withdrawal of Royal Air Force Puma helicopters from Belize in 1994, the role of casualty evacuation passed to 25 Flight Army Air Corps, who were equipped with Gazelle helicopters. Whilst the Puma is a large twin-engined helicopter, the Gazelle is a small, single-engined observation and reconnaissance aircraft.

Details of the casualty evacuations carried out during 1995 and 1996 were collated and analysed in order to provide information on casualty types, and the locations from which casualties had been evacuated, during this 2 year period.

A total of 192 casualties were transported by 25 Flt AAC. Of these, 119 were British military personnel, 49 were Belizeans and 24 were foreign nationals. Thirty six evacuations took place wholly or partly at night. The majority of British military evacuations took place from jungle or mountain locations, predominantly for accidents or heat illness. Evacuations of Belizeans were mostly from town or jungle locations and foreign nationals from the cayes. The commonest cause for both these groups was accidents.

The data were used to ensure the provision of an appropriately equipped CASEVAC helicopter, and to highlight common causes of significant morbidity in British troops deployed to Belize.

Background

Belize is a developing country to the East of Guatemala and South of Mexico in Central America, approximately the size of Wales, and with a total population of some 216,000. The country's topography can be divided into 4 main regions: a northern flat plain, with some cultivated areas and other areas covered in dense scrub and trees; a central mountain range, with steep sided hills covered in dense secondary jungle; a more undulating southern region, also covered in secondary jungle; and a low coastal plain covered in mangrove swamp. There are, in addition, hundreds of small islands, or cayes, strung along the longest barrier reef in the western hemisphere.

The climate of Belize is tropical, hot and humid. Daytime temperatures range from 25 to 35°C during the year, remaining high throughout the night in the lower-lying areas but falling to 4°C in the mountains. Relative humidity is consistently in the high 90%s. The rainy season is between June and January, although tropical storms produce heavy rainfall throughout the year, and the hurricane season occurs between July and November.

The Belizean economy is based mainly on agriculture, especially on sugar cane and citrus fruits, although tourism is becoming increasingly important with growing recognition of the natural assets of the unspoilt interior of the country, and the beauty of the cayes and reef. At present the majority of tourists originate from the United States.

The Belizean population is divided so that approximately half live in the 7 major cities, with the remainder in a number of smaller towns, and small isolated settlements in remote areas. Hospitals are located in Belize City, Belmopan, Punta Gorda, Orange Walk, and Dangriga, although only the former has facilities to deal with significant trauma or surgical, medical or obstetric emergencies. Transport communication between the centres of population is improving, but remains very poor by western standards. The majority of the lengths of the 4 national highways is unmetalled, with frequent potholing, and impassable flooding after tropical storms. Road travel times between the more distant major centres and Belize City

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may exceed 12 hours, and night-time travel is particularly hazardous.

Helicopters have a number of uses in casualty care: Improvement of response time where casualties are in remote areas; earlier delivery of advanced medical intervention; increased speed in transportation of the casualty; direct delivery to the most appropriate specialist centre; and inter-hospital transfers (1). It is now well-recognised that the prognosis for injured casualties is worsened by delay in receiving advanced medical care. For severely injured patients, the mortality rate has been observed to increase by 300% for every 30 minutes' delay in treatment, and the use of helicopters for rapid evacuation of casualties in conflict has been given as the most likely cause of the progressive reduction in casualty mortality rates (2).

Until late 1994, a helicopter Search and Rescue and casualty evacuation service was provided to British and Belizean Military personnel, Belizean civilians (including the Belize Defence Force or BDF) and foreign nationals (predominantly tourists but also including British nationals on Operation Raleigh, and staff of the British High Commission) by the Pumas of 1653 Squadron, Royal Air Force. 1653 Squadron was based at Airport Camp, some 20 minutes by road from Belize City. The Puma is a large Support Helicopter with a crew of 3, and a seated passenger capacity of 14. In addition, the Puma can be fitted with a winch which is clearly invaluable in operations over dense jungle terrain. The Puma support was withdrawn with departure of the RAF contingent from Belize in 1994. At this time the role of providing a 24 hour casualty evacuation service[1] for the entire country was passed to 25 Flight, Army Air Corps who are currently equipped with Gazelle helicopters. The Gazelle is a small light reconnaissance helicopter, with a crew of one or 2 pilots, and further seating for 2 passengers. If a lying casualty is to be carried, the left-hand front seat and flying controls are removed, and a Bofors Splint stretcher must be used in order to fit the casualty's feet into the small rear baggage space. This leaves room only for a single seated attendant in the rear, who has restricted access to the patient in flight. For night CASEVACs of a lying casualty, single-pilot Night Vision Goggle (NVG) flight must be carried out. This is a risky procedure which is not generally permitted in other theatres of Army Air Corps operations. There is no facility for winching from the Gazelle, so for jungle evacuations either the patient must be transported through the jungle to a cleared area, or a new landing site area cut laboriously from the jungle at the pick-up point.

Despite the apparent constraints on carriage of casualties in the Gazelle, 25 Flt AAC have been regularly, and successfully, tasked with CASEVAC since the departure of 1653 Squadron in 1994. This paper analyses the details of helicopter CASEVACs carried out by 25 Flt AAC during 1995 and 1996.

Results

During 1995 and 1996 a total of 192 casualties were evacuated by the Gazelles of 25 Flt AAC. These have been broken down into population groups (British military/dependants, Belizean nationals, and foreign nationals including British civilians), into diagnostic groups, and according to location from which the evacuation took place (jungle, mountains, cayes or towns).

Records for 1995 show that 77 British military, 23 Belizeans, and 13 foreign national casualties were evacuated, totalling 113 persons. For 24 of these evacuations, part or all took place at night. In 1996, the total of 79 casualties was comprised of 42 British military personnel, 26 Belizeans and 11 foreign nationals. Twelve of these CASEVACs took place at night. Over the 2 years, 6 casualties were BDF or MoD Employees (included in the Belizean national totals), and 5 were British expedition members on Operation Raleigh (included in the Foreign national totals).

The predominant causes for evacuation of British military personnel were injury resulting from accidents (62 in total over the 2 year period, representing 52%), and heat illness (25 casualties over 2 years, or 21%). The most common categories for Belizean casualties were accidents (16, or 32%), and obstetric emergencies (9, or 18%). Foreign nationals were also most likely to require CASEVAC following accidents (8, or 33%), with medical problems (5, or 21%) as the second commonest cause. Scrutiny of the causative factors in more detail reveals that over the 2 year period, 18 of the British military casualties were evacuated for eye injuries caused by tree sap, released whilst cutting jungle foliage. A number of these were injured after cutting a jungle landing site for evacuation of a colleague.

Most British military casualties were evacuated from jungle locations (89, or 75%), or mountain sites (18, or 15%). Belizean nationals were most likely to require evacuation from towns (21, or 43%) or jungle locations (18, or 37%). In contrast, foreign nationals were CASEVACed predominantly from the cayes (11, or 46%).

Victims of assault, and obstetric patients were evacuated from only town or caye locations, whereas accident victims were distributed amongst all 4 location groups: jungle, mountains, cayes and towns. Heat casualties, food poisoning cases and victims of bites or stings were almost exclusively rescued from jungle locations, and medical and surgical problems were more

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[1] A limited casualty evacuation service is provided for civilians, in daylight hours only, by a small fixed-wing aircraft operated by a local tourist air-charter company. This can only operate where casualties are close to an airstrip which are generally located only near the major population centres.

likely to result in CASEVAC from jungle sites, but also occurred at the other location types. Not surprisingly, all 3 diving casualties (decompression illness) were evacuated from the cayes.

Of the 89 CASEVACs of British military personnel from jungle locations, 41 (46%) were for accidents, 24 (27%) were heat casualties, 8 were for food poisoning and 8 for medical problems (9% each), 5 (6%) had been bitten or stung and 3 (3%) had surgical problems.

Discussion

The data on casualty types collected during the first 2 full years of Army helicopter casualty evacuation in Belize might be used to ensure provision of an appropriate service in the future, and possibly to attempt to reduce future casualty rates. Every evacuation flight, particularly at night, exposes both crew and medical staff to personal risk, and of course involves significant financial cost.

The primary role for 25 Flight AAC is evacuation of British military casualties, who are predominantly personnel undergoing jungle training. In order to carry out CASEVAC from remote jungle locations, helicopters should be fitted with task-specific equipment which is currently lacking in the present aircraft, namely winching equipment capable of lifting casualty and attendant; sufficient cabin space to allow in-flight resuscitation and treatment; and capacity for two-pilot night operations whilst carrying patient and attendant, to reduce the potential hazards inherent in night jungle landings.

The evacuation of local or foreign casualties is a lesser, but still significant, priority. Such evacuations predominate from town or caye locations, which do not present the same technical difficulties as flight into jungle landing sites.

Whilst the majority of British military casualties evacuated by helicopter are victims of injury or accident in the jungle, there has been a significant number of CASEVACs for potentially preventable problems. Over a quarter of the evacuations from the jungle were for heat illness, and a further 9% were due to food poisoning. Education of all personnel, and in particular the chain of command, concerning risks of heat illness and the importance of field hygiene, should remain a vital component of pre-deployment briefings. A total of 14 evacuations of military casualties (from jungle and mountains) were for medical or surgical problems, despite the continuing requirement that only personnel who are FE should be sent to Belize.

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	Accidents	Assault	Heat	Bites/ Stings	Diving	Med	Surg	Obstetric	Food Poisoning
1995	43	0	14	4	0	8	0	0	8
1996	19	0	11	3	0	4	4	0	1
Total	62	0	25	7	0	12	4	0	9

Table 1. British Military CASEVACs 1995/6 by cause.

	Accidents	Assault	Heat	Bites/ Stings	Diving	Med	Surg	Obstetric	Food Poisoning
1995	7	1	2	0	1	1	4	4	3
1996	9	4	0	1	0	5	2	5	0
Total	16	5	2	1	1	6	6	9	3

Table 2. Belizean National CASEVACs 1995/6 by cause.

	Accidents	Assault	Heat	Bites/ Stings	Diving	Med	Surg	Obstetric	Food Poisoning
1995	3	2	0	1	2	2	2	0	1
1996	5	0	0	2	0	3	1	0	0
Total	8	2	0	3	2	5	3	0	1

Table 3. Foreign National CASEVACs 1995/6 by cause.

	Jungle	Mountain	Cayes	Town
1995	54	17	4	2
1996	35	1	1	5
Total	89	18	5	7

Table 4. British Miltary CASEVACs 1995/6 by location.

	Jungle	Mountain	Cayes	Town
1995	7	0	7	9
1996	11	0	3	12
Total	18	0	10	21

Table 5. Belizean National CASEVACs 1995/6 by location.

	Jungle	Mountain	Cayes	Town
1995	3	0	6	4
1996	4	0	5	2
Total	7	0	11	6

Table 6. Foreign National CASEVACs 1995/6 by location.

	Accidents	Assault	Heat	Bites/ Stings	Diving	Med	Surg	Obstetric	Food Poisoning
Jungle	49	0	26	8	0	12	8	0	11
Mountain	11	0	1	2	0	3	0	0	1
Cayes	12	3	0	1	3	3	1	3	0
Town	14	4	0	0	0	5	4	6	1

Table 7. CASEVACs 1995/6: Totals by Location and Cause.

Something new - all together!

The Rotterdam HEMS perspective.

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Abstract

The Rotterdam HEMS has been operating since August 1 1997. It is a pilot project for the Netherlands South West, meant to improve the delivery of prehospital care and closely monitored by the Ministry of Health, the Air Force and Navy. Over 650 flights have been made in the first year, mostly first response flights and missions at the request of ambulance services on-scene. Increasingly, interhospital transfers and on scene thrombolysis are being performed, however. This article focuses on the organizational aspects, as well as training and quality assurance of the program.

The 3 member crew consists of a pilot, EMT-nurse and a senior resident of the University Hospital anesthesiology program, 2 of whom are Dutch military flight surgeons, USN and USAF trained, respectively. Required medical training beforehand included ATLS, ACLS as well as aeromedical transport and Emergency Medicine experience. The training program for the crew included teambuilding, under water escape training and in-house crewmember cross-training, so that essential crew tasks can be performed by all, both in flight as well as on the ground. Another crewbuilding experience was ICET-training, where advanced extrication techniques were practiced. Crew Resource Management programs are being developed, since standard industry programs are not applicable. The concept of HEMS in a densely populated country like the Netherlands has met with some fierce resistance in local ambulance services and dispatchers, making it necessary to come up early with a well-defined educational and information providing program. Quality assurance (QA) is an important issue. Cases are extensively reviewed, beginning with after-action debriefing sessions with ground EMS-personnel. Evaluation involving all crewmembers and patient follow-up after the incident is standard. Some highlighted cases are regionally discussed in monthly review sessions with ambulance crews and dispatchers from the area of operation. We feel a pro-active approach, including QA, is essential for long term success.

Introduction

The Rotterdam Helicopter Emergency Medical System (HEMS) project finally took off on August 1, 1997 – finally indeed, because preparations had been going on for almost a year. This service was the second civilian one to become operational in the Netherlands, after the first pilot project had been started in the Amsterdam area. Eventually, the whole country of the Netherlands is meant to be covered by four civilian HEMS services, each covering a 60-70 km radius area (see figure 1).

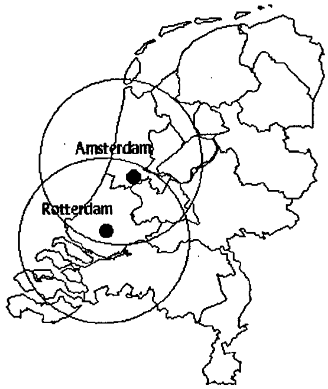

Figure 1. The Amsterdam and Rotterdam HEMS

Background

Where did it all start?

Up to 1996, civilian expertise with aeromedical operations in the Netherlands was limited to a select group of health professionals, most notably the University Hospital of the Free University (Amsterdam) and the Erasmus University (Rotterdam). Anesthesiology departments in both hospitals have a reputation to uphold regarding long distance retrieval of critically ill patients from abroad. Virtually all these flights were conducted in fixed-wing aircraft, most of them in commercial aircraft. Sometimes dedicated ambulance charter aircraft were used. Rotary wing aeromedical experience could be found in the Royal Netherlands Navy as well as the Air Force, both services being committed to Search and Rescue Operations over the North Sea, one of the busiest sea lanes in the world, as well as the northern Wadden islands. Medical evacuation of civilian sailors and fishermen, as well as inhabitants of the remote Wadden islands, gave the military flight surgeons involved ample experience with the benefits and dangers of delivery of medical personnel to the patient, as well as transportation through the air. However, flying "medevacs" is not the primary mission for the military, hence much time was inevitably lost in converting the aircraft from military to aeromedical configuration or longer alert times than desirable. Occasional aeromedical missions were flown at the explicit request of civilian authorities (e.g. the Bijlmermeer El Al cargo plane crash in 1992 and disaster relief during flooding in the South as early as 1953 and much later in 1994 and 1995), but it was not until 1996 that a dedicated HEMS service was borne. Relatively late for a developed country like the Netherlands, a fact that can probably be explained by the fact that this is a densely populated and highly urbanized country: 373 inhabitants/sq km, with 89% of the population living in an urban area. It features abundant hospital coverage and well organized ambulance services. Interestingly, most of the population is concentrated in the western provinces of North Holland, South Holland, and Utrecht, comprising the large urban region called Randstad Holland. This is the exact same area, which is now covered by the first two HEMS services.

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The experimental status

As early as the early-eighties isolated military experiments were undertaken in the Netherlands to initiate HEMS. The Air Force embarked on a trial in the northern provinces, a relatively sparsely populated area of the Netherlands. Only for the Wadden islands, the need for aeromedical intervention capability was eventually recognized by the Ministry of Health and funding for continuation of the program was found, at first using a Allouette, later a Augusta Bell 412. An initiative by NAS Valkenburg in cooperation with the Rotterdam University Hospital department of Anesthesiology to establish a planned aeromedical interhospital transport service for a similar region in the Southwest using a Lynx helicopter failed in 1989. The same hospital undertook a 3 month feasibility study in 1995, using a commercial helicopter company, which clearly established a need for fast, reliable interhospital transportation of a select group of critically ill patients needing sophisticated medical intervention, thereby bypassing a road-congested area. Interestingly, this study, where operations were restricted to daylight hours, also indicated that the need for this kind of service would be even greater after sunset. The Rotterdam University department of Anesthesiology already had a long term interest in aeromedical evacuation, which started of in the eighties, having retrieved a vast number of Dutch nationals from all over the world. For 1998 the expected number of medevacs performed is expected to exceed 300 for the first time, lately involving more and more foreign nationality patients, who are transported to their home country by a Dutch team.

By 1995 the ANWB (the Dutch Motorist Organization), in close cooperation with the German ADAC Luftrettung GmbH helicopter service (which has a long reputation in civilian HEMS in that country), became the driving force for a Dutch HEMS equivalent. In fact, both Amsterdam and Rotterdam started of with German Eurocopter BO-105 helicopters. The experiment was also partly funded by the Ministry of Health, the University Hospital of the Free University provided surgical and anesthesiology staff and residents as well as Emergency Room nursing personnel. Later ambulance EMT-s were added to the nursing pool of the crew.

Rotterdam

A strong promoter for the Rotterdam project was the EBB, an organization meant to safeguard the interests of the Rotterdam harbor area, still one of the largest in the world, stretching for almost 60 km from coast to city. A vast number of people live in the middle of numerous high-tech petrochemical industrial activities, as well as maritime activities. The need for highly specialized medical intervention for workers in case of an accident was readily acknowledged by this group. Another force in support of this project was the city of Rotterdam, aware of the ever-growing congested traffic situation in the area. Both Navy and Air Force, each having a flight surgeon in clinical specialty training in Rotterdam (both in anesthesiology) encouraged the development of HEMS.

Specific elements

Early on in the project's development attention was focused on some specific elements in this new HEMS:

1) The objective is to bring highly specialized medical personnel to the patient, rather than transport the patient by helicopter to specialized care.
2) Criteria for scene flights, possibly a major part of the workload, are meticulously described.
3) Trauma is an important, yet not the only field of interest. Hence, we are not a "trauma team". It also includes:
    a) Inter-hospital transfer (according to strict criteria) of trauma victims and ICU patients.
    b) Advanced cardiac care: e.g.12 lead EKG, defibrillator: on scene thrombolysis[1] and selection for rescue-PTCA.
    c) Advanced pain management (using opioid titration and locoregional techniques)
    d) Advanced airway management[2]
    e) Specific attention for:
        i) pediatric care (i.e. a low threshold for activation of the team in case children are involved[3 4 5 6]
        ii) Acute medical diseases in which early advanced medical care might improve outcome, like drowning, attempted suicide by means of medication, etc.
        iii) Industrial toxicology hazards

HEMS operation limitations

Medical Air Assistance B.V. has received its Aircraft Operating Certificate January 1, 1998 for a VFR-day only HEMS operation. The Dutch Aviation Law normally does not allow VFR night flights and civilian low-level ops. However, the Dutch Aviation Authorities (RLD) granted the following waiver especially for HEMS operation:

1) To perform VFR flights outside the Universal daylight period. During VFR night flights the HEMS limitations are: visibility min. 5000 m, cloud base min. 1000 ft and horizontal distance to the clouds min. 1500 m.

NB: The HEMS can be activated from 07:00 to sunset, but due to operational constraints, this is limited to 19:00 hours. Activation after sunset is not permitted; a mission that has been started before sunset, however, can be completed by one take-off and landing (usually the return-to-base flight).

2) To perform flights below the minimum VFR altitudes.

a) Over urbanized and congested areas: 1000 ft above the highest obstacle within a 600-meter radius.
b) Outside urbanized and congested areas: a minimum of 500 ft AGL.

When due to the cloud base those requirements can not be met, those altitudes may be reduced to:

i) 500 ft AGL to a minimum of:
ii) 100 ft AGL with no obstacle within a 100m radius from the helicopter.

During operations under these conditions, special routes in the CTR's are established.

3) To perform a low visibility operation.
   a) Weather limitations for the HEMS operation during the daylight period are:
      i) Minimum visibility inside the CTR: 1500 meters (Special VFR and designated routes)
      ii) Cloud base 500 ft within CTR, outside CTR cloud base may be 200 ft.
   b) At all times the flight shall be executed clear of clouds and in continuous sight of ground or water.

And:

1) Only one authority can be approached (by other dispatching services, hospitals etc.) to activate the team: the Rotterdam-Rijnmond Dispatching Center.

The Team

The pilots

The HEMS operation in the Netherlands started May 1, 1995 from a base on top of the Hospital of the Free University in Amsterdam. The flight operation was carried out with a Bölkow BO 105 CBS on the AOC of KLM ERA Helicopters. At that time KLM ERA Helicopters was the only civil operator in the Netherlands, which operated two BO 105 CBS. Those two BO 105's were unemployed in the hangar and were leased to ANWB/Medical Air Assistance to start the HEMS operations. The KLM ERA company was bought by Schreiner Airways in January 1998 and is now called Schreiner North Sea Helicopters. Its main activity is serving the offshore installations in the North Sea. Selection of the pilots took place under responsibility of the head of Operations of KLM ERA. Although JAR-OPS 3 is not yet mandatory, the requirements laid down in JAR-OPS 3 for pilots were implemented as much as possible.

The selection criteria and specific qualities sought after for pilots to start this HEMS operation were:

1. A minimum of 1500 hrs flying experience, of which a minimum of 1000 hrs as pilot in command and 500 hrs experience on turbine helicopters,
2. Sufficient VFR and low altitude flying experience. Pilots with a military, law enforcement and offshore background are preferred as opposed to pilots with mainly air transport experience, since the latter group's experience has been build up mostly under IFR conditions. The first group comes with an abundance of VFR and low altitude experience, flying under adverse circumstances as well as knowledge of the local area.
3. Willingness to be available to do extra work, especially in the build up phase of this HEMS operation. A Special Operation Manual and Protocols had to be written
4. The capability to work in a team and be a team player.
5. A high index of stress resistance.

One senior captain of KLM ERA became the chief pilot HEMS and the base manager of the HEMS station at Amsterdam and one pilot was hired from KLM ERA. An ex-Air Force pilot with a lot of experience as a search and rescue pilot in the Air Force completed the first team. Training of the pilots started in January 1995 with the recurrent type training on the BO 105 CBS. Special attention was paid to the single engine procedures, confined area operation, and emergency procedures. A Flight Safety course for the crew relevant to the HEMS operation was developed during this time.

In the beginning of 1997 the preparations of the Rotterdam base were started. By then, the selection of the pilots of this station was no longer the responsibility of the Head of Operations of Schreiner Northsea Helicopters, but of the Director of ANWB-MAA. Although not many pilots were and are available in the Netherlands to fly HEMS, four new pilots fitting the profile were contracted. Two of them started at the Amsterdam location, two of them in Rotterdam. The chief pilot and base manager of the Amsterdam team now became base manager of Rotterdam. The training of the new pilots was done by the ADAC Luftrettung GmbH., the German sister organization of the ANWB-MAA.

The doctors

As outlined above, a lot of preliminary work had fortunately already been done by August 1, 1997. The experience drawn from military SAR activity, as well as the 1995 study and the aeromedical retrieval program was put to good use. It was decided to start with a small group of decidedly interested physicians, who met the following criteria:

Selection criteria for physicians:

1) Resident in Anesthesiology or Surgery Program
2) At least three years of clinical experience, of which at least 6 months in an anesthesiology program and 6 months emergency medicine/surgery/trauma care or intensive care.
3) ATLS provider, preferably instructor
4) ACLS provider, preferably instructor

5) ICET (International Center for Extrication Techniques) qualified, preferably International Instructor.
6) PALS provider
7) HAZMAT trained
8) Participation in aeromedical transport program.
9) Knowledge of/experience with prehospital care (LOTT/ "crashteam"/MMT or EMT-experience)
10) Communication procedures trained
11) Flight-safety awareness
12) Disaster medicine awareness
13) Team player
14) Stress resistance
15) Multilingual

The team includes 7 anesthesiology residents and 1 medical director. Two of the residents were USN and USAF trained flight surgeons, respectively. All had extensive knowledge of Emergency and prehospital medicine, including ATLS and ICET. PALS, ACLS and HAZMAT certification was a problem, since those programs weren't started in the Netherlands at the time. The team had to make do with alternative training available, self-education and relevant experience. During this prep phase, HAZMAT turned out to be quite closely related to military NBC-courses. All in all, in our opinion the specialty most qualified to provide an additional benefit to advanced patient care in a prehospital setting is an anesthesiologist. This was also the opinion of several ambulance services when asked whom they would prefer to have on scene with them.

The flight nurses

There is no such thing as a civilian flight nurse program in the Netherlands. On the other hand, there is a multitude of qualified personnel working as ambulance EMT-P. It was decided to select interested individuals from strategic services in the region and train these people in country, not only medically (in and outside the hospital), but also by means of flight training.

Selection criteria for the nurses were:

1. Registered Nurse
2. Certified Intensive Care Nurse or Certified Anesthetic Nurse.
3. At least two years experience in the ambulance service
4. Certified as an ambulance nurse
5. ATLS attendant
6. ACLS provider
7. PHTLS
8. ICET (International Center for Extrication Techniques) qualified
9. HAZMAT trained
10. Navigation and communication certified
11. Flight Safety program
12. Disaster medicine (TML certified)
13. Team player
14. Stress resistance
15. Multilingual (English/German)

The flight training of the EMT-P's in Rotterdam started in February 1997 with a 4 weeks navigation course at one of the Dutch flying schools. This course consists of navigation, aerodynamics, meteorology, aviation law and basic radio communication procedures. Navigation was practiced during 10 hours actual flying with instructor in a fixed wing aircraft. Actual navigation in the area of operation was performed during the training phase ahead of the start of the actual operation in the BO 105 CBS.

Why not use qualified EMT's and dispense with the doctors?

Having doctors on board seems to be a European way of doing HEMS, as opposed to the paramedic - flight nurse combo in the USA. To name a few: the UK, Norway, Switzerland and Germany all fly a physician program. One of the reasons is medico-legal in origin: advanced medical procedures, which are normally a specific task for hospital based physicians, cannot be expected to be performed by nursing or paramedic personnel on a planned basis. The philosophy is based on the premise that anywhere in the Netherlands patients can be brought promptly to a hospital after merely lifesaving paramedic ambulance care. Therefore, all advanced medical procedures have to be done in the hospital within the first 15 minutes after bringing the patient into the hospital. We, however, think advanced medical care should and can be available at an earlier stage outside the hospital by dedicated trauma oriented physicians. Although apparently strictly European, some US-programs fly doctors as well, though, mostly ER-residents. Years ago, in an early article about the Birmingham (Alabama, USA) program this "complete team approach" was highly recommended[7]. According to this article the physician "upgrades the level of care at the scene of an accident, lessens the referring physician's anxiety, maintains an intensive care unit environment during transport and intervenes if a life threatening emergency occurs, which cannot be predicted prior to lift-off." Kelley[8] in his textbook states: "Emergency physicians supervise the medical care provided by prehospital personnel who practice under their licenses. Direct physician involvement also is necessary in other aspects of these, including protocol development, transport issues, personnel training, quality improvement, and disaster planning." In our opinion you should practice what you preach and be where the action is: on-scene. Therefore we bring the physician to the patient, not the other way around.

Why use EMT-P's as opposed to critical care or anesthesia nurses?

Firstly, there is a definite ambassadorial function to be performed by our flight nurses. They are the liaison between the hospital and the ambulance community. Secondly, most of our EMT-P's did acquire these qualifications previously to starting their EMT-P career.

Starting a HEMS station

The challenge

As outlined above, the team's objective is to bring specialized personnel on scene, not to provide a luxurious, albeit somewhat dangerous, novel form of patient transportation. Many community hospitals cannot sustain the effort to maintain a 24 hour team of health care professionals, serving a maximum 10 k radius area, who can move out by car and provide emergency and critical medical care outside the hospital and during transport out on the street to a patient trapped in a vehicle, for instance. One team from a larger university hospital, using a helicopter, can cover a large area, in our case one with a 60-70 km radius.

Conflicting emotions are abundantly present when starting HEMS. Care should be taken to approach the subject in a rational, rather than an emotional or prejudiced manner. This apparently is a rather difficult requirement for services and individuals involved. Firstly, for instance, for local authorities (hospital as well as municipal) the imminent danger is to see helicopter transportation as a fancy new "thing to have". A "me-too" approach conceivably means safety is quickly compromised if, for instance, only limited funds are available. During our first year in operation one of the regions in Zeeland, the southernmost and very water-rich province decided they wanted to have their own service available as a back-up to their ambulance service, especially during the busy beach season. A helicopter was chartered and local nurses without aeromedical training or experience were invited to hop in on a need to fly basis. This approach is highly undesirable, in our opinion. We believe safety and QA is and should always be of the foremost importance.

Secondly, when a hospital-based service like HEMS is started in a hospital and ambulance dense country like the Netherlands in the nineties, one shouldn't be surprised to see some very emotional reactions among hospitals, ambulance services and dispatchers. Why do we need university hospital know-it-alls prying into our business? Are you telling us we cannot do our job out on the street without assistance? What do you know about working in the prehospital setting anyway? Commercial concerns also arose. The fear that patients would be abducted by helicopter to an out of the region university hospital stirred up some hefty primal reactions, both with the ambulances and the regional hospitals.

What did we do to overcome this? Before we even started, an aggressive information campaign was initiated. All the hospitals (ER and trauma departments), local dispatch and ambulance services in the South-West were approached. Information was given about the capabilities of this new service, continuously emphasizing that the only one to possibly benefit from this had to be the patient, not one health provider or the other. Information packages with suggested criteria to ask for HEMS assistance were widely distributed. We also stressed in our contacts with regional services and the media that advanced patient care is a team effort: this had been published as early as 1976[9] [10]. HEMS cannot work without the full cooperation of ambulance, dispatch, police and fire services in the region[11]. Numerous visits were paid by the team by helicopter to cities in the area to personally meet officials. A carefully orchestrated media campaign established good press coverage and thus a high profile in the weeks around August 1 1997.

Interestingly, the modern ways of electronic communication provided us with some very useful suggestions. Posting our concerns on FlightMed, an Internet listserver (Listserv@rotor.com) dedicated to HEMS, numerous HEMS experienced colleagues from England, Germany, Norway and of course the USA came to our help, giving detailed advice and encouraging us to persevere in our efforts. As can be seen from the results, this paid off in the end.

To promote our views in the ambulance and dispatching services, introductory flight sessions were organized, where interested members of all services could fly with us for one day to experience our views and capabilities first hand, as opposed to hearing it through the grape vine. As will be shown in the results, this may have helped us quite considerably. It definitely helped us to gain acceptance in the ambulance and dispatching services.

We also emphasize the importance of discussing our approach with all services involved on a regular basis. Apart from short after-action debriefing sessions with ground EMS personnel, every other month a review session is held. Here theme based cases (e.g. penetrating chest wounds, extrication, difficult airway etc.) from the recent past are discussed in an open forum, stressing the importance of close cooperation between all services. The involved prehospital services are all invited, as well as the receiving hospital departments (ER, Surgery and Anesthesiology Departments). By presenting case files, we try to open the discussion, inviting the audience to participate and ventilate their views. This promotes mutual understanding into each other's views, resulting in an even more coordinated action on-scene. Take for instance entrapment of victims in a vehicle: only by close cooperation of all parties can <30 min extrication be realized[12]. Knowing EMS-personnel on a personal basis in your area helps promote mutual understanding of techniques and procedures and speeds up operations tremendously. Our latest session welcomed some 140 attendants, some of whom had to travel over 3 hours one way. Feedback shows this is a well-appreciated effort.

Training and Safety issues

Being the first HEMS service in a region, all the above is particularly important. It could be argued that previous military and partly experiments had failed because an aggressive, more commercial approach is needed to get lift-off. On the other hand, previous military experience with SAR and involvement in repatriating Dutch nationals, both civilian and military paid off in starting this project. As a flight surgeon first and anesthesiology resident second, we think safety is of critical importance. Knowing how dangerous medevac flight ops can be we insisted on proper relevant training for all crewmembers. The military forte is safety, where civilian programs excel in professional medical training[13 14]. Bringing the two together should provide the best of both worlds and in this program, we feel our input did make a difference. This experience can in turn then be capitalized upon in out of area operations[15] like the Balkan, where the military does need sophisticated medevac capabilities[16]. A high quality approach, rather than a strictly wartime large-scale way of thinking is preferable here. It serves as a booster for morale and is therefore of direct military benefit.

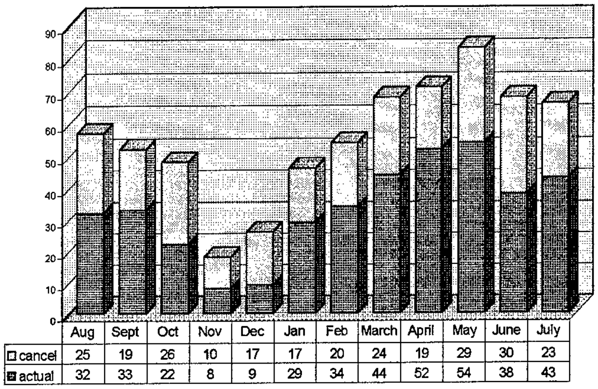
A cooperation with the chief pilot a flight safety course was provided. Geographically, we serve a water rich environment. A ditch training course, using the Air Force BO-105 mock up was followed by all. Nomex gloves and helmets were introduced and a long discussion about the usefulness of full Nomex coveralls and flotation devices was started. Suggestions by EBB we should also perform hoist ops (for ships in the harbor region) were strongly discouraged from our side, considering the risks involved. Hoist operations are not specifically a military specialty: mountain rescue services have practiced it for a long time. It does, however, bring in a dangerous element to a crew not specifically trained in this area. All in all, we think the military flight experience contributed to this program was of paramount importance to the success of the program.

A CRM-program is under development and will be implemented shortly. Group discussions (after action debriefs among all crew as well as with the other services involved) are standard practice and give valuable insight in how this novel approach to patient care is perceived and how we can further bundle our collective efforts to improve it, focusing on safety as well as patient care.

Results

From August 1, 1997 to August 1, 1998 657 missions were flown, of which 398 (60.6 %) resulted in an "actual". The remaining 259 "cancels" (39.4%) were cancelled for various reasons, often because the first arriving ambulance did not deem helicopter use necessary, but also because patients had already expired before arrival. The number of missions flown per month is depicted in Figure 2. The graph shows an interesting phenomenon: the so-called "mid-winter dip", for which various causes can be responsible. Firstly, fewer incidents seem to happen in these months anyway. Secondly, exactly in those months a strong anti-HEMS lobby gained considerable momentum. Disbelief that this project had actually started after all was replaced by strong words about the project, resulting in fewer calls to the scene and more cancellations of the mission by the ambulance, some of them actually doing that before they arrived on the scene themselves. Thirdly, the introductory flight sessions for ambulance crew members and dispatchers were started. Hugely popular, they provided valuable word of mouth promotion as to our intentions. These sessions had to be stopped temporarily for the summer season because of weight limitations of the aircraft by the end of May.

Figure 2 Missions per month



	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July
☐ cancel	25	19	26	10	17	17	20	24	19	29	30	23
▨ actual	32	33	22	8	9	29	34	44	52	54	38	43

The total number of patients treated over the period was 455, more than the total number of actual missions, because several incidents involved more victims at once. A total of 53 (11.6%) patients died on scene or shortly after arrival in the hospital. Of the 455 patients seen, 373 (82%) were transported by the ambulance services, 39 were transported by helicopter (8.6%), mostly because of the lengthy distance from the scene to the nearest adequate hospital. Lastly, 43 patients were transported neither by helicopter nor by ambulance because of death on the scene. Of the 39 patients transported by helicopter, 20 were transferred from one hospital to a tertiary care center. If we exclude these, a total of 19/455=4.2 % of the scene flights resulted in helicopter transport. In 225 cases the physician accompanied the patient in the ambulance. In our opinion, it can therefore be safely concluded that the ambulance services did not suffer major economical damage because of HEMS introduction.

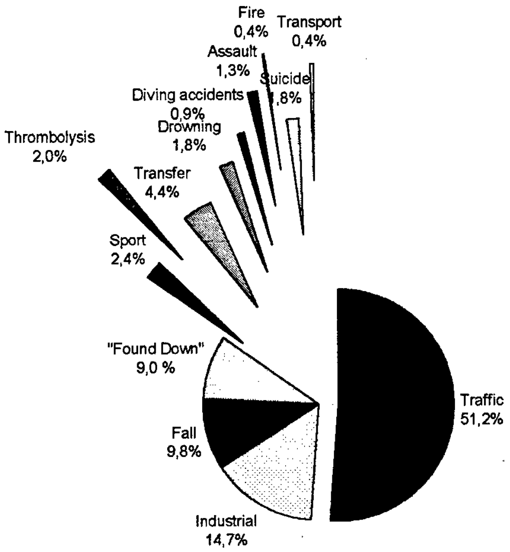
Surprisingly, the average response time and on scene time were remarkably constant. Instead of a "learning curve" they equaled approximately 10 and 30 minutes respectively. September shows a longer on scene time, caused by two complicated entrapment cases that month, with stable patients. Pain relief and circulatory support could be given while fire crews worked hard to free the patients.

Mission Times in minutes:

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Year Average
Av. Response	0:10	0:11	0:12	0:09	0:09	0:08	0:10	0:10	0:10	0:09	0:12	0:09	**0:10**
Av. On Scene	0:32	0:46	0:33	0:34	0:31	0:39	0:30	0:31	0:32	0:33	0:31	0:33	**0:34**

Figure 3 presents a breakup in selected incident categories over the year. As can be seen traffic is the major contributor to the missions flown. Next are industrial accidents, partly coming from our sponsor EBB's area the Rotterdam Harbor area, but also in considerable numbers from other industrial area's. As can be seen from the graph a perhaps higher incidence than usual of diving accident (0.9%) and drowning (1.8%) emphasize the fact we serve a water-rich environment. The transport category represents two incidents where on specific and urgent demand specialized university hospital surgeons were flown to a rural hospital. There they assisted in the operation of a patient in critical condition who was too unstable to be transported.

Figure 3 Incident categories



During our first year in operation there was a highly skewed male-female ratio: of the 438 recorded cases 340 (77.6%) were male, the remaining 98 (22.4%) female. We encountered 24 children under 10 years old, 5 of which were under the age of 1. The oldest patient we saw was 92 years old and involved in a traffic accident. He was successfully extricated. The number of entrapment cases numbered 82 (18.0%). Patients were intubated in 106 cases (23.3%), received a chest drain in 14 cases (3.1%) and were administered pain relief 164 times (36%).

For the future

The first of August '98 saw the finish of our first year in HEMS. It didn't give us the certainty our project can be continued in the future. A political decision still has to be made. Is HEMS really worth the effort? Does it save lives? And if so at what cost? The first results from the Amsterdam HEMS[17], comparing HEMS patients with matched ambulance controls showed that the HEMS cost turned out to be approximately \$20,000-\$40,000 per life saved and per year won. This is an acceptable figure, if compared to other health care interventions. It was also noted that with the present daylight hours operations at about 30% of all multiple trauma victims were treated in the area. The Rotterdam HEMS was studied by another group[18] which has tried to narrow down the indications for HEMS-use, based on the most successful interventions over the past year. Discussion has also sprung up about the feasibility of nighttime ops. At present, we can only return to our home base during darkness, but perhaps interhospital transfer can be performed safely during these hours. Nighttime scene flights are still some time away. However, the RLD, the Dutch equivalent of the American FAA, has refused all of this so far.

Conclusion

The gut feeling that we could and personal experience that we did make a difference in numerous cases has been proven scientifically now in the Amsterdam study. We can further their work by narrowing down the indications were patient benefit is most likely. In our opinion, we have established a win-win situation. Firstly this fledgling HEMS (and therefore our patients!) benefited from relevant previous experience from the military and the specialty of anesthesiology. On the other hand, this first year of HEMS gave invaluable prehospital experience to military flight surgeons and residents in anesthesiology. In our opinion, advanced prehospital care is a growing field, which cannot be ignored. As for the military, in a military world undergoing negative growth the applied training of individuals for highly specific tasks such as specialized prehospital care is a rare opportunity that should not be missed. This investment in human capital is well worth the effort.

Abbreviations:

ACLS: Advanced Cardiac Life Support
ADAC: German Motorist Association
AGL: above ground level
ANWB: Dutch Motorist Association
AOC: Aircraft Operating Certificate
ATLS: Advanced Trauma Life Support
BO-105 CBS: extended version of the Messerschmitt-Bölkow-Blöm type 105 aircraft.
CRM: Crew Research Management Training
EBB: Europoort Botlek Belangen (a lobby group for the Rotterdam Harbor area)

EMT-P: Emergency Medical Technician-Paramedic
HAZMAT: Hazardous Materials Training.
HEMS: Helicopter Emergency Medical Service
ICET: International Center for Extrication Techniques, Raamsdonkveer, the Netherlands
JAR-OPS 3: Joint Aviation Requirements - Operational Procedure Standards, 3rd revision.
LOTT: up to July 1998 the National Committee for Prehospital Trauma Teams, after that MMT (Mobile Medical Team).
PALS: Pediatric Advance Life Support
QA: Quality Assurance
RLD: The Dutch Aviation Authorities (the equivalent of the American FAA)
SAR: Search and Rescue

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RECUPERATION ET SAUVETAGE DE COMBAT :EXPERIENCE DE L'AERONAUTIQUE NAVALE EN ADRIATIQUE.

COMBAT SEARCH AND RESCUE IN NAVAL AVIATION : ADRIATIC EXPERIENCE.

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1. Sommaire

Depuis 1994, deux avions de reconnaissance du groupe aéronaval déployé en mer Adriatique ont été touchés par des missiles antiaériens au dessus le l'ex-Yougoslavie. L'extraction de personnels de territoires contrôlés par des forces inamicales est ainsi devenu d'actualité.

Mener à bien des secours en zone hostile nécessite l'utilisation coordonnée de matériels et de savoir faire très divers dont peu de pays disposent. Ces missions de REcupératiopn et Sauvetage de COmbat (RESCO) peuvent être effectuées de manière autonome et avec peu de préavis à partir d'un groupe aéronaval centré sur un porte-avions qui dispose de tous les éléments nécessaires:
-un état-major et ses cellules renseignement et météo.
-un détachement d'hélicoptère Super-Frelon. Cet hélicoptère de transport tactique offre une grande flexibilité opérationnelle avec sa vaste cabine accessible par les portes latérale et arrière. L'équipage est entraîné à voler sous Jumelle de Vision Nocturne (JVN).
-une flottille de Super-Etendard qui assure l'appui aérien.
-des appareils de guet aérien avec radar embarqué (actuellement le Breguet Alizé et prochainement le Grumman E-2C).
-des forces d'interventions avec un détachement de Commandos Marine à bord.
-un support médical avec les équipes médico-chirurgicales du porte-avions rompues aux missions de secours en mer (SAR).

Tous ces personnels, de l'Amiral aux pilotes, mais aussi les commandos, les officiers de renseignement, les médecins, vivent, travaillent et s'entraînent ensemble quotidiennement sur le porte-avions. Nous présentons les procédures, la coordination et la confiance mutuelle développées entre ces protagonistes pendant les déploiements du groupe aérien en Adriatique pour cette mission pluridisciplinaire. Nous avons par exemple développé une régulation médicale spécifique au RESCO, avec un autobilan médical codé et des techniques d'oxyologie adaptées à l'utilisation des JVN et aux contraintes tactiques des opérations héliportées.

En conclusion, d'après notre expérience, un groupe aéronaval déployé à proximité d'une zone hostile est un outil sophistiqué adapté à conduire avec un court préavis une mission de RESCO.

2. Abstract

Since 1994, two naval reconnaissance aircrafts from French carriers deployed in the Adriatic have been damaged by enemy fire over former-Yugoslavia. Retrieving military personnel from enemy lines became a topical issue.

Rescuing people in a hostile zone requires a wide spectrum of equipment and skills, in a highly coordinated operation that few countries can afford. Such a Combat Search And Rescue (CSAR) mission can be conducted autonomously and at short notice by US or French carriers, since they carry all the required assets :
- command and control with the Commander Task Force and his head quarters, including intelligence and weather forecasting.
- a Super-Frelon helicopter squadron. This tactical transport helo provides a large cabin with lateral and back doors which allow flexibility in operational use. The crews are trained to fly with Night Vision Goggles (NVG).
- an attack squadron with Super-Etendard fighters which provide a combat air patrol capability.
- an airborne radar (currently Breguet Alizé and by the end of 1998 the Grumman E-2C).
- commandos with a Marine Commando detachment on board.
- medical support with the carrier medical and surgical team, familiar with Search And Rescue missions.

All these personnel, from Admiral to aircrew, commandos, intelligence and medical officers are used to living and practicing together in the confines of a carrier. We discuss skills, coordination and trust developped during Adriatic deployments for this multidisciplinary mission. As a result we field an optimized CSAR medical system which uses a coded medical report, and specific procedures adapted to NVG environment and tactical helo operations.

Therefore, from our experience, a carrier group, operating close to a hostile shore, is a sophisticated finely tuned tool, adapted to conduct a short notice CSAR operation.

3. Mots clés / Key words

RESCO, porte-avions, évacuation médicale.
CSAR, aircraft carrier, medevac.

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4. Texte

4.1 Introduction

Depuis 1994 lors des opérations en mer Adriatique, quatre Etendard du groupe aéronaval ont fait l'objet de tir par missile à guidage infrarouge (2 avions ont été touchés et 2 autres ont évité l'impact). Avec trois avions abattus (Mirage 2000, Harrier, F16) le conflit en ex-Yougoslavie a réactualisé le CSAR (Combat Search and Rescue) ou RESCO (REcupération et Sauvetage de Combat). Cette mission se traduit par la récupération en zone hostile d'un ou plusieurs pilotes éjectés, mais aussi de commandos infiltrés ou de personnalités sensibles. Le RESCO dans l'Aéronautique Navale a donc connu des évolutions, bénéficiant de l'expérience acquise lors des nombreux entraînements conduits de manière autonome ou avec l'armée de l'Air, l'US Air Force ou l'US Navy. Le médecin du personnel navigant (PN) du porte-avions, et le chirurgien de la Force d'Action Navale (FAN) étant impliqués systématiquement dans la préparation de la mission, le concept de médicalisation de cette mission a lui aussi évolué.

Le déclenchement de l'alerte RESCO est provoqué par l'état major du CTF (Commanding Task Force), qui active ainsi la cellule RESCO du porte-avions, composée des représentants des opérations (renseignements, vols, météo...) du groupe aérien (avions et hélicoptères), du détachement de commandos marine, et du médecin du PN. Cette cellule va analyser les paramètres tactiques et médicaux, puis va élaborer un plan de manoeuvre qui sera proposé au CTF, qui décidera de l'exécution de la mission et choisira les différentes options qui lui sont présentées.

La mission RESCO pourra être conduite avec un très faible préavis du fait du fonctionnement autonome du groupe aéronaval, qui dispose des avions d'appui aérien (Super-Etendard), de guet aérien (Alizé et bientôt E-2C), des hélicoptères de transport tactique qualifiés vol avec jumelles de vision nocturne (Super-Frelon), et des forces d'intervention (commandos marine). La mobilité du porte-aéronefs permet d'adapter le transit des Super-Frelon aux contraintes tactiques.

4.2. Rôle du médecin PN

4.2.1. analyse des conditions de survie

Le médecin du PN agit comme un expert, il aura la charge d'interpréter d'un point de vue médico physiologique les paramètres de l'environnement naturel et tactique. Les prévisions météorologiques seront analysées: température, altitude, vent, hygrométrie sont des facteurs majeurs dans le pronostic de survie lié au délai de récupération parfois repoussée de plusieurs jours, et aux blessures éventuelles pouvant limiter les possibilités de recherche d'un abri par le rescapé. Les conditions de l'éjection seront étudiées afin d'apprécier le risque de traumatisme lié à l'abandon de l'appareil: altitude, vitesse, attitude de l'avion, type de relief pour l'atterrissage, cause de l'éjection. Le médecin va donc traduire tous ces paramètres en termes de temps de survie et de lésions potentielles, ce qui influencera bien sûr les choix des options dans la préparation de la mission.

4.2.2. régulation médicale

Comme pour une intervention de secours maritime, le RESCO fait l'objet d'une véritable régulation médicale. A chaque contact radio entre le rescapé et les secours (aéronefs, troupes au sol), le pilote donnera sous forme d'un code alpha numérique son état clinique. Ce code appelé « auto-bilan » ou physical status, porté par tous les pilotes de l'Aéronavale, résume en 26 items les signes fonctionnels les plus probables dans le contexte du RESCO. Même si toute la sémiologie ne peut être couverte ainsi, ce code a l'avantage d'être concis, et obéit donc à l'obligation de discrétion et de rapidité des communications avec le rescapé, il est facilement cryptable, et peu sensible à la déformation. En effet, l'expérience prouve qu'un message à caractère médical retransmis par plusieurs intermédiaires non sensibilisés à ce type de régulation, et c'est le cas de tout contrôleur opérationnel, subit des déformations majeures, le rendant peu fiable. Par ailleurs en étant alpha numérique, il est facilement transmis par des opérateurs non francophones, ce qui est souvent le cas dans le cadre d'opérations interalliées, il est donc adapté aux théâtres multinationaux. Ce code est finalement adressé à la cellule RESCO du porte-avions où il sera interprété par le médecin, qui en suivra l'évolution dans le temps. Le médecin analysera, avec l'aide de la cellule « renseignements », la carte des structures médicales alliées dans la zone, en fonction de leur accessibilité par hélicoptère (influencée par la météo, la distance, les obstacles tactiques) et de leur plateau technique (chirurgies spéciales, neurochirurgie, chirurgie viscérale, vasculaire).

Tous ces éléments médico-tactiques intégrés, le médecin proposera un type de médicalisation. La règle sera de limiter cette médicalisation à l'infirmier breveté commando qui accompagne systématiquement le dispositif de récupération, exceptionnellement le médecin sera intégré à cette équipe si sa présence améliore significativement le pronostic vital ou fonctionnel du rescapé.

4.2.3. préparation de la manoeuvre

Une fois décidé le type de médicalisation, le <u>déroulement de la mission</u> sera revu, phase par phase, en choisissant les options les plus opportunes. La méthode de débarquement du commando par posé de l'hélicoptère, corde lisse ou rappel, sera prédéterminée en fonction du type de terrain, du temps autorisé sur zone, du signalement éventuel de mines. La vaste cabine du SF, avec ses accès latéraux, arrière et de plancher autorise une grande souplesse d'utilisation. Les modalités du conditionnement initial du rescapé et de sa récupération dans le Super Frelon (SF) seront choisies: treuillage à la sangle, civière souple ou hélitreuillable, dispositif d'immobilisation adapté de type Ked ®.

Le médecin complétera en fonction du contexte clinique supposé le <u>matériel</u> de l'infirmier commando, il lui déléguera, si l'option sans médecin est retenue, des gestes thérapeutiques adaptés qu'ils auront revus ensembles.

Si l'option avec médecin est choisie, ce dernier sera équipé et instruit par les commandos sur les conduites à tenir sur zone en cas d'incidents et l'exécution des plans d'évasion et récupération différée.

Le type d'éclairage dans le cargo du SF et sur le terrain sera discuté. La mission RESCO privilégiant la discrétion, cette dernière sera le plus souvent effectuée de nuit et sous jumelle de vision nocturne (JVN). L'équipe médicale devra donc pendant le survol de la zone hostile se soumettre à cette contrainte supplémentaire, d'où l'entraînement auquel nous nous sommes astreints en réalisant les gestes techniques d'urgence (mise en place d'une voie veineuse, préparation de drogues, suture...) sous JVN et en vol. Ce type de préparation est nécessaire car conditionner un patient sous JVN, avec les vibrations et les mouvements de cabine lors des vols tactiques est source de fatigue visuelle et cervicale, et de cinétose.

Une fois préparée, la mission est soumise au CTF, qui décide donc des modalités de l'exécution de la mission.

4.2.4. exécution de la mission

Le transit aller est mis à profit pour déconditionner le matériel médical, préparer les drogues en fonction de la pathologie attendue et des antécédents du blessé. Le lot médical du médecin, quand celui-ci est engagé dans l'exécution de la mission est spécifique au RESCO : conçu pour prendre en charge pendant quelques heures un ou des hommes jeunes sans états morbides antérieurs, et présentant une pathologie essentiellement traumatique.

La récupération proprement dite devra limiter le conditionnement initial au minimum afin de respecter les contraintes de temps sur zone, garantes de discrétion, donc de sécurité. Exceptionnellement le médecin peut être amené à descendre sur le terrain, voire à rester avec le commando et le blessé, surtout en cas de récupération différée.

Lors du transit retour, après le traitement initial et la stabilisation du patient, le médecin ou l'infirmier communiqueront le bilan clinique, au chirurgien qui préparera l'accueil technique du blessé.

La coordination entre l'équipe médicale, l'équipage et les commandos est un facteur essentiel de succès. Les déploiements sur porte-avions qui permettent de vivre et travailler ensemble pendant des semaines offrent des conditions uniques pour cultiver cette confiance mutuelle qui s'instaure entre pilotes, commandos, état-major et médecins.

4.3. Conclusions

Le RESCO est donc une mission de combat dont la composante médicale ne peut être ignorée. Le médecin du PN intégré systématiquement à la préparation de la mission agira d'abord comme expert médico-physiologique en traduisant en terme de risque vitaux ou fonctionnels pour le rescapé, les paramètres environnementaux naturels et tactiques et le bilan lésionnel apprécié par auto bilan codé. La médicalisation sera confiée à l'infirmier commando, le médecin ne participant à l'exécution de la mission que si des risques vitaux ou fonctionnels majeurs pour le rescapé peuvent ainsi être évités. Le CTF, conseillé par le chirurgien, pourra apprécier les options proposées, et décider du type de mission la plus adéquate.

Coordination et confiance mutuelle sont des facteurs de réussite majeurs pour ce type d'opérations complexes. Le porte-avions, en permettant aux différents protagonistes du RESCO (commandos, pilotes, officiers d'état major, médecins...) de bien se connaître, car vivant et travaillant ensemble, est un excellent catalyseur.

Le secours maritime pratiqué par les médecins de l'Aéronavale, où certaines contraintes du RESCO sont retrouvées (temps limité, environnement hostile, régulation aléatoire, compromis techniques) représente certainement la meilleure préparation de temps de paix. Réciproquement, les procédures développées pour les missions RESCO, tels que les matériels développés pour conditionner les blessés, la régulation médicale par bilan codé, sont sources de progrès pour les secours médicaux en environnements extrêmes.

Les caractéristiques techniques du vecteur (autonomie, volume de cargo disponible, accès au cargo, systèmes de communication) conditionnent directement le type de récupération. Le compromis efficacité/sécurité de la mission sera meilleur avec un hélicoptère lourd ou de moyen tonnage permettant une grande souplesse de configuration.

An Analysis of the Impact of Chemical/Biological Warfare Environments on Aviation Crewmember Cockpit Performance

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INTRODUCTION

In 1995 and 1996 Bell Helicopter Textron conducted studies to determine the effect of NBC environments on aircraft cockpits and on aircrew performance. Two of the studies concentrated on:

1. Determining the build up rates inside small non hardened helicopter cockpits and
2. Determining the effects of the chemical protective clothing individual components on aircrew performance.

The First study was used to determine the performance requirements for chemical detection systems.

The second study was used to identify the short comings of existing chemical suits used by aviators and quantify those shortcomings in order to recommend improvements in future designs.

The studies were intended to be generic in nature and apply to non- hardened scout type aircraft.

The first study used the cockpit specifications and ventilation systems of a Jet Ranger type aircraft to determine the expected build up rates of chemical agents in the cockpit given a specific exterior contamination level.

The task lists and manuals for the OH58 D Kiowa helicopter were used to provide input data for the Task and Workload analysis in the second study.

The build up study determined the rate at which agent built up in the cockpit These data were plotted against the casualty effects of the specific agent as reported in standard military field manuals, and the exposure times were used to calculate the sensor response time requirements. The requirements were for the sensors to provide the crew adequate warning in both point and remote sensing modes.

If adequate warning can be provided, aircrews can fly into suspected contamination areas in a lower protective posture and, as the warning is provided, they can maneuver to avoid the contamination or increase the personal protection to a higher level. For example, the crew may fly with the protective mask off and the protective suit open to provide cooling and until the moment the protection is required. This capability can improve both mission endurance and crew efficiency.

This paper reports briefly the methodology used and the expected effects of one specific agent, and reports in detail on the methodology and the results of a human performance modeling analysis.

The human performance analysis was conducted to determine the workload impact of each level of the mission oriented protective posture (MOPP) equipment on the task performance of helicopter crewmembers, flying a small scout helicopter in a chemical environment.

The original analysis was expanded as part of the early requirements definition phase of the US Army Air Warrior Program.

This paper will report some of the analysis results only. Except for examples, the analysis data, detailed task list, etc. are not included in this paper.

THE CHEMICAL ENVIRONMENT IN NON-HARDENED SCOUT COCKPITS

CHEMICAL BUILD RATES

The following 70-Knot (kn) Build-up evaluation data is extracted from a memo to the author from Dr. Robert Shepherd of Bell Helicopters Operations Research group. The data were used by the author to derive response requirements for chemical sensors and for interior contamination evaluations.

The data represents the GB (Sarin) portion of a 70-knot profile of the scout helicopter in a chemical environment. The data illustrates the build up rate and the probable effects on the crew if they are not protected by the chemical ensemble.

The helicopter is assumed to be flying along a path near the burst centers of the chemical delivery systems in this worst-case scenario, taking the pilot through the highest concentration levels after a near miss attack. The scenario used a concentration level near a burst center of about 1,540 mg/m^3 as a starting point for the analysis

The data in Table 12-1 is used as the casualty producing concentrations and is based on data in the U.S.Army Field

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Manual FM 3-9, *Military Chemistry and Chemical Compounds*, Table 2, "Properties of Chemical Agents." The analysis concentrated on how much time is required for the build up of chemicals in the cockpit to reach casualty producing levels. The time required to reach levels were determined for lethal exposure, incapacitating exposure and, miosis.

Table 12-1. Characteristic Resting-Man Exposures for Gb

LETHAL ($mg{\cdot}min/m^3$)	INCAPACITATION ($mg{\cdot}min/m^3$)	MIOSIS ($mg{\cdot}min/m^3$)
100	75	1

An approximation of the buildup rate was derived using the following assumption:

1. The aerosol will not permeate the cabin by diffusion; instead, it will be introduced and distributed by forced ventilation.
2. The scout helicopter cabin is essentially an air duct. Air primarily enters through two inlets in the nose and exits out the aft section.
3. Airflow from the door vents and cabin leaks were assumed to be zero, thus all air flow into the cabin was attributed to the two blowers in the nose section.

The airflow rates were determined from test data and the cockpit volumes were derived from aircraft drawings. The total volume of the sections making up the cockpit add up to 75.2 cubic feet.

Given the volume of the cockpit, and the incoming airflow rates estimates were made for the time required for all the air in the cockpit to be replaced with contaminated air from the outside, i.e., the time required for the GB concentration inside to reach the same 1,540 mg/m^3 level as the outside. The results are given in Table 12-2

Table 12-2. Buildup Rates For The Cockpit at 70 Kn.in a 1,540 Mg/M^3 Cloud of Gb Nerve Agent

CONDITION	70 KIAS
INFLOW (cfm.)	187.2
VOLUME (cu. ft.)	75.2
EXCHANGE TIME (min)	0.4
MAX GB LEVEL (mg/m^3)	1,540
BUILDUP RATE (mg/m^3min)	3,850

Using the 70 KIAS data as an example, and assuming a constant buildup rate, the GB level inside the cockpit will behave similar to the curve shown in Figure 12-1

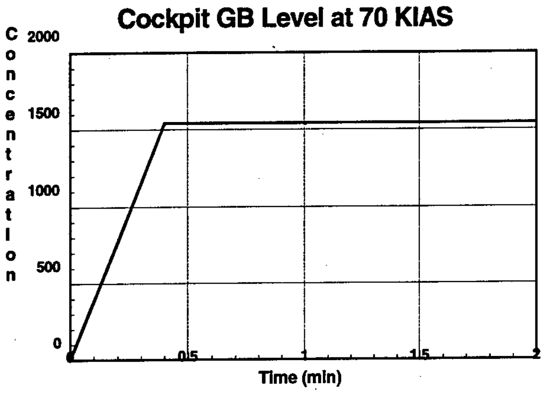


Figure 12-1. GB Concentration Inside the Cockpit vs. Time

The total exposure to the pilots is computed by integrating the area under this curve for the duration of the exposure.

Exposure values for the first few minutes at 1-minute intervals are shown in Table 12-3.

Table 12-3. Exposures for Pilot in 1540 mg/m^3 GB Cloud ($mg{\cdot}Min/m^3$)

CONDITION	70 KIAS
1 Min.	1,232
2 Min.	2,772
3 Min.	4,312
4 Min	5,852
5 Min.	7,392

PROBABLE CASUALTY EFFECTS

The causality data in US ArmyFM 3-9, indicates the pilot will inhale several times the lethal dose in his first breath.

Within approximately 2 minutes after the initial exposure, miosis symptom first appears. If the exposure occurs in daytime, he may still be able to see well enough to withdraw from the contaminated area. However, if his first warning that he is in a contaminated area is the onset of miosis, he has, by this time (t = 2 min.), inhaled about 30 times the lethal dose (LD)

Incapacitation will likely occur before the pilot can safely touch down since the other symptoms (vomiting, convulsions, loss of bladder control, etc.) usually manifest from 2 to 5 minutes after exposure possibly rendering the crew incapable of flying the aircraft. If the pilot survives the probable crash, he will die of respiratory failure within 15 minutes of the initial exposure.

Exposure times for lethal, incapacitation, and miosis levels are listed in Table 12-4 for four given flight conditions. For example, the table shows that at 70 knots, the GB level inside the cockpit will reach the miosis level in only 1.4 seconds. Assuming about a 2 second inhalation, the pilot can easily draw enough GB to be blinded with his first breath once he's entered the toxic cloud.

Table 12-4. Exposure Times for Scout Pilot in 1,540 mg/m^3 GB Cloud

CONDITION	LETHAL (sec)	INCAPACITATION (sec)	MIOSIS (sec)
Flat Pitch	16.6	14.4	1.7
IGE Hover	16.8	14.5	1.7
OGE Hover	15.9	13.8	1.6
70 KIAS	13.7	11.8	1.4

Figure 12-2 shows two curves representing exposure times for the 70 KIAS case as a function of the concentration of GB outside the cockpit. The dashed line shows the time when the miosis level is reached; the solid line shows when lethal exposure occurs. Figure 2 may also be used to determine the time available prior to incapacitation for any given exterior concentration. For example, a helicopter traveling at 70 kn. is traversing the terrain at approximately 35 meters a second. Given a contaminated area 500 meters long, it will take the aircraft approximately 14 seconds to pass through the contamination. Using the chart in Figure 12-2 it may be seen that if the level of exterior contamination is greater than 50 mg. per cubic meter, the crew will have been exposed to a concentration several times the miotic dose and most likely will have received an incapacitating dose due to the residual agent in the cockpit during the time it takes to transient the contaminated area.

In the absence of sensors that can detect the agent at least 40 to 60 seconds before it reaches the miotic level, prudence demands the aviator fly into suspected contamination completely protected from the chemical environment.

The next section of this paper deals with an analysis to determine the effects of each level of NBC protection on mission and task performance.

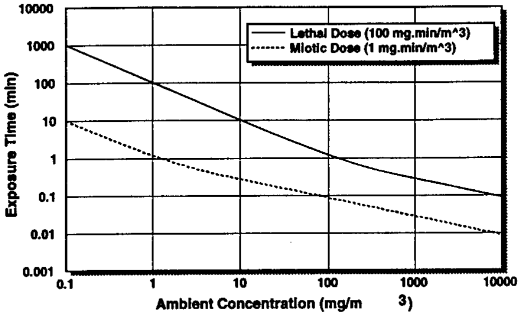


Figure 12-2. Expected Exposure at 70 Kn

MISSION TASK ANALYSIS METHODOLOGY

The mission task analysis conducted for the aircraft were modeled on the OH-58D Kiowa crew task list with the crew operating in both standard and chemical environments. The analysis concentrates on a scout attack mission that requires the aviators to perform start and run-up procedures, take off, navigate and cruise low-level to a target area, engage a threat and return to base.

The analysis was conducted using a mission scenario incorporating the standard tasks described in the scout helicopter training manuals. (1)

The analytical method used in the study is pragmatic, combining the relevant data from current mission / training documents and aircraft handbooks with HFE analytical tools.

These tools included standard handbooks, operations sequence diagrams, evaluations on existing hardware, simulators and computer modeling.

Mission tasks were defined to the 3rd level (detailed checklist identification) by subject matter experts having recent field experience in scout and attack aircraft. These experts were Master Army Aviator Standardization Instructor pilots. The task lists prepared by the experts were evaluated and several typical tasks were selected for evaluation to the 4th level to determine those tasks which, when not performed, or not performed in the required sequence or time, could result in adverse effects to:

a. Operator safety
b. Mission performance
c. System accuracy

Selected critical tasks required to operate the Mission Equipment Package (MEP) and the aircraft were identified to the Therblig element level (individual motion/action/reaction) and incorporated into the workload model. Each task was fully defined per the Engineering Work Measurements Standard and appropriate Baseline (non-NBC) times applied.

The assigned baseline time to perform each task was based on: (1) Times specified in standard human factors engineering manuals and literature, modified as required by the actual timing of some of the operation measured in the mockup, simulator or actual aircraft. (2) Times required to perform the task, based on Methods Time Measurement

(MTM) methodology (MTM Association 1987) handbooks or the MTM data resident within the workload model.

WORKLOAD ANALYSIS METHYODOLOGY

When the task procedures were fully defined, the procedures and time lines were programmed into a the workload model and processed in a Monte Carlo fashion to determine the work load, performance times and Probability of success for each task. This established the Non- NBC environment workload baseline against which the NBC baseline could be compared to quantify the effect of the various MOPP levels on aviator performance

Definition of Workload.

Workload in the analysis used the following definition. The analyst used, with some modification in the secondary task and mental task definition, the Chiles and Alluisi definition of workload which states; "the level of operator workload is assumed to be determined by the aggregate of occupational demands placed on the worker. The actions required of the worker, or operator, may be physical, cognitive, sensory-perceptual, perceptual-motor, verbal, concrete, or symbolic - or they may be some combination of these. Occupational demands are presumed to require some action (either overt or covert) on the part of the worker, with the performance of the job or work compromised if the demand is not met by an appropriate worker action or reaction. 'Demands' that do not require action are not really demands at all."

Modification to the secondary task analysis consists of inserting forcing factors other than the primary task to determine points of over loading, i.e. inserting additional flight plan routing or similar changes that require very high communications workload while performing normal operator duties. In addition to secondary task, continuous tasks such as flying the aircraft low level while performing the discrete task, were inserted into some of the task descriptions. These insertions were done in certain cruise/attack flight segments in order to force the division of operator attention while performing the discrete task much as occurs in actual flight. This was required to determine the time, workload and probability of success in a flight environment. This division of attention required to perform discrete tasks while performing the continuous tasks of flying the aircraft is consistent with actual flight requirements on military missions.

Modification to the mental loading is the assumption that any task which requires a physical action also requires a mental (cognitive) awareness of that action. Thus every task has some level of cognitive loading defined in the input data.

WORKLOAD ANALYSIS MODEL

Sequitur's Workload Analysis System (SWAS) is used at Bell Helicopter as a method for determining task timelines and time-based workload estimates and "bottlenecks." The model is appropriate for operator, maintainer, and support personnel, and considers equipment time as part of the timeline (i.e., focuses on system performance in addition to human performance). Input estimates for task element time performance (means and standard deviations) may be based on subjective estimates, empirical data, or the Methods Time Measurement (MTM) methodology (MTM Association, 1987); SWAS incorporates a module for automatically calculating MTM estimates of task element times.

SWAS compensates for many of the shortcomings of earlier workload models by incorporating principles from human information processing, statistical sampling theory and Monte Carlo procedures, multidimensional scaling, and artificial intelligence into modeling the timelines and workload estimates. SWAS considers both inter- and intra-operator timesharing in its modeling and uses workload demands to modify the performance requirements.

SWAS performs a simulation and analysis on a task segment; i.e., a file containing a meaningful series of task elements with coded attributes. Each discrete task element in the segment contains its associated mean performance time, standard deviation, and human information processing requirement codes (visual, or audio inputs, spatial or verbal processing and audio or manual outputs for the discrete task element and any continuous task being concurrently performed). Additionally, task precedence codes are attached to provide sequence control within and between operators. SWAS also provides a number of run time options for addressing "what if" questions regarding the wearing of Nuclear, Biological, and Chemical (NBC) protective clothing, and individual difference variables (User defined).

SWAS results provide various statistics regarding system workload/performance, information processing requirements, and performance "bottlenecks," It then produces an accurate timeline for the task segment. A variety of descriptive statistics are provided for the principal measure of workload (time required divided by time available); in addition, the probability of successfully performing the task within the time available is produced. Taken together, these results provide analytical data to support design and development decisions.

MOPP LEVEL DEFINITION

In order to evaluate the effect of the various MOPP levels on the aviator, it is necessary to define the levels as aviators in the field use them. Because of the circumstances of flight, the Aviation levels differ from those defined in U.S. Army FM 1-101. (See Table 12-5).

Table 12-5. Mopp Level Requirements Per U.S. Army Field Manual 1-101

MOPP LEVEL	1	2	3	4
OVER GARMENT	W (O)	W (O)	W (O)	W (C)
OVERBOOTS	C	W	W	W
MASK/HOOD	C	C	W	W
GLOVES	C	C	C	W

W= WORN W(O)= WORN OPEN or CLOSED
W or W (C) =WORN CLOSED C= CARRIED BY USER

The MOPP level 1 specified in the field manual is not practical for aviators flying in smaller cockpits or single pilot aircraft since it is not possible to safely don the overboots once seated and strapped into the cockpit. Therefore, MOPP level 1 is eliminated and MOPP 2 is the lowest practical level that can actually be used in the cockpit.

Another Modification to the MOPP level is at level 3. FM 1-101 states the mask should be worn but not the gloves. In Aviation, vision is critical and the mask tends to reduce the aviator's field of view. In addition the mask causes some physiological stress. Therefore, the mask is not donned until level 4 protection is required.

The reason for requiring the gloves be worn at level 3 in aviation is the difficulty of donning the gloves while flying low-level. In many cases small scout helicopters are flown with a non-pilot observer, rather than a co-pilot. Donning gloves requires the pilot to release one or more flight controls for extended periods in order to don the gloves and can affect flight safety. They may be donned at higher altitude prior to reaching the engagement zone if the tactical situation permits.

Based on informal interviews with several aviators, MOPP level 3 is usually omitted and the aviator flies in MOPP 2 when there is low probability if encountering CW, and MOPP 4 when there is a high probability of such encounter. The stated reason for doing this is due to the fact that no detectors other than paper are available and high levels of some agent vapors can be encountered before warning is given by such devices.

Table 12-6. Illustrates the MOPP levels as used by scout pilots during operations scenarios.

Table 12-6 Aviation Mopp Level Analyzed

MOPP LEVEL	1	2	3	4
OVER GARMENT	W (O)	W (O)	W (O)	W (C)
OVERBOOTS	C	W	W	W
MASK/HOOD	C	C	C	W
GLOVES	C	C	W	W

W= WORN W(O)= WORN OPEN or CLOSED
W (C) =WORN CLOSED C= CARRIED BY USER

For This Analysis a MOPP level "0" was constructed in which the aviator is dressed in normal flight attire but has the NBC garments on board the aircraft. The level "0" also serves as a benchmark against which the other levels can be measured to determine the effect of the various suit components on task performance.

WORKLOAD RESTRICTIONS AS A RESULT OF MOPP LEVELS

The NBC protective suit limits motion / reach, tactile dexterity and visual field of view. Each of these factors affect the time required to perform a given task. These factors must be accounted for in any NBC related task analysis. The following considerations were accounted for in the analysis.

MOTION / REACH

Due to the bulkiness of the current NBC protective suit ,overhead reach is more difficult than with the normal flight suit. Informal interviews with aviators indicate this is especially true of fresh (new) suits. As a result, tasks requiring overhead reach were coded as "some what difficult" verses "easy" (Based on the standard MTM case data) in the computer model. Since overhead reach is required for many tasks during the prestart, engine start and run-up, and pre taxi phase of flight operations, the affect of the suit is most pronounced in this portion of the analysis.

TACTILE DEXTERITY

The protective gloves used with the NBC ensemble are stiff, hazardous materials handlers type, rubber gloves. They are worn over an insert glove or the aviators flight glove. The bulkiness and thickness results in a loss of tactile feel and an increase in the square area covered by the fingertips. Most switches in modern cockpits are similar to computer keys, or are closely spaced miniature toggles and rocker types. Care must be taken not to activate adjacent switches when performing cockpit operations while wearing NBC gloves. This deliberate care results in some small time increase (within the model) to perform each task when operating in MOPP 3 or 4. The tasks were coded in the computer similar to the codes for Motion / Reach.

VISUAL FIELD OF VIEW

The mask and hood tend to reduce the aviator FOV and require the head to be moved in order to see some switches that normally may be seen by simply shifting the eyes to the region. In addition greater motion is required to bring items with in the FOV than would be required if the mask were not worn, especially when glancing downward. The Nose and mouth portion of most masks intrude into the downward FOV and require significant head motion when compared to non-NBC requirements. These motions require additional time (fractions of seconds in most cases). These small incremental increases tend to increase the workload over the baseline task due to the fact that the time required to perform the task increases while the time available to do the task remains unchanged in the analysis.

Table 12-7 illustrates the restrictions applied at each MOPP level.

Table 12-7. Task Performance Restrictions as a Result of Mopp Level

MOPP LEVEL	0	1	2	3	4
REACH		X	X	X	X
TACTILE				X	X
VISUAL					X

X= Significant impact

TASK LISTS AND ALLOCATIONS

The detailed task list and allocations are not provided as a part of this paper however an example of the level of detail assigned to each task is shown in Figure 12-3. The segment illustrated is part of the before start checklist.

ANALYSIS RESULTS

Each mission task was analyzed four times. Once for baseline and once for each MOPP level. The maximum nominal time required to perform a task (produced by the MOPP 0 analysis) was used as the time available baseline for the MOPP 2, 3, and 4 task analysis. Table 12-8 and Table 12-9 provides a summary of each analysis and probability of successful completion within the required time. Note any workload above 1 indicates excessive workload is required to meet the time limit.

It should also be noted that the probability of success drops significantly when the Time available remains at the MOPP Zero Baseline. In several instances the time available had to be doubled to achieve Ps >.85

The following figures (graphs) illustrate the data to permit comparison of tasks and MOPP levels.

Figure 12-4 illustrates time required comparison between MOPP levels for the tasks required to prepare the aircraft for takeoff. The code identifiers are:

1 <u>Before engine start 1</u>: Those tasks associated with entering the aircraft, strapping , locking the armor plate and closing the doors.

2 <u>Before engine start 2</u>: Those tasks associated with cockpit interior checks prior to adding electrical power and immediately after electrical power is applied.

3 <u>Before engine start 3</u>: Those tasks associated with electrical, instrument and mechanical systems prior to actual engine start.

4 <u>Engine Start</u>: Those tasks associated with the actual engine start and adjusting engine to flight idle RPM.

5. <u>Engine run-up</u>: Those tasks associated with checking the flight control and engine run-up

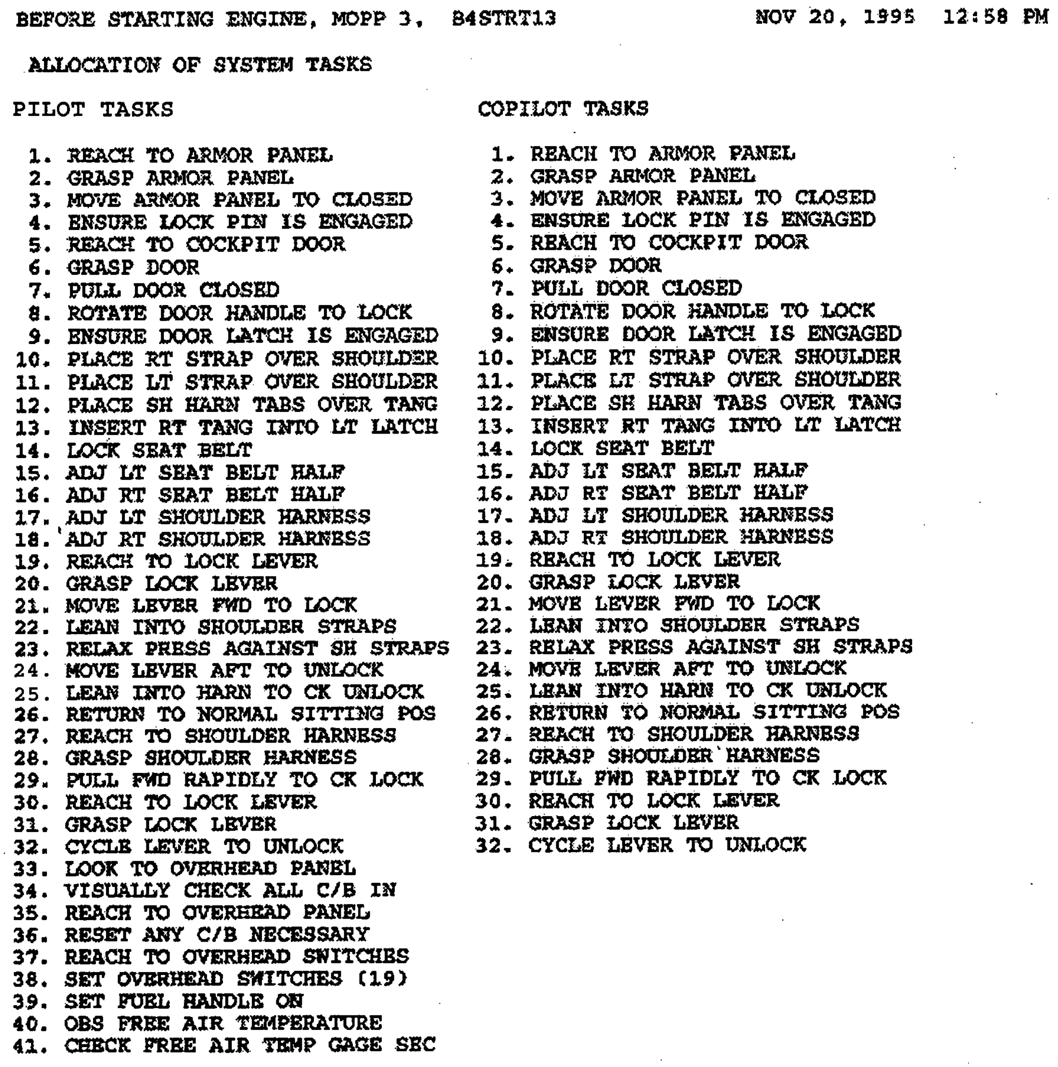
6 <u>Systems checks</u>: those tasks associated with checking the aircraft avionics and electrical systems prior to flight. (Note; many of these tasks require overhead reach to the systems panel located on the overhead panel).

Each MOPP level is illustrated. MOPP 0 is the baseline analysis that assumes normal flight suits and gloves. MOPP 2 through 4 adds pieces of the NBC gear as described in Table 12-2

The largest increase in time required is between MOPP 0 and MOPP 2. This can be attributed to the stiffness of the NBC suit and the restrictions to overhead and cross cockpit reach (note SYSCHKS). In those task groupings not requiring overhead or cross cockpit reach the change in not as dramatic.

The increase between MOPP 2 and MOPP3 can be attributed to the increase time required to manipulate switches, press buttons etc. While avoiding inadvertent activation of adjacent controls.

The increase in time between MOPP 3 and MOPP 4 can be attributed to the head movement required to visually locate switches or similar vision restrictions caused by the mask that are less pronounced when operating in MOPP 0.



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BEFORE STARTING ENGINE, MOPP 3,  B4STRT13               NOV 20, 1995  12:58 PM

 ALLOCATION OF SYSTEM TASKS

PILOT TASKS                        COPILOT TASKS

 1. REACH TO ARMOR PANEL            1. REACH TO ARMOR PANEL
 2. GRASP ARMOR PANEL               2. GRASP ARMOR PANEL
 3. MOVE ARMOR PANEL TO CLOSED      3. MOVE ARMOR PANEL TO CLOSED
 4. ENSURE LOCK PIN IS ENGAGED      4. ENSURE LOCK PIN IS ENGAGED
 5. REACH TO COCKPIT DOOR           5. REACH TO COCKPIT DOOR
 6. GRASP DOOR                      6. GRASP DOOR
 7. PULL DOOR CLOSED                7. PULL DOOR CLOSED
 8. ROTATE DOOR HANDLE TO LOCK      8. ROTATE DOOR HANDLE TO LOCK
 9. ENSURE DOOR LATCH IS ENGAGED    9. ENSURE DOOR LATCH IS ENGAGED
10. PLACE RT STRAP OVER SHOULDER   10. PLACE RT STRAP OVER SHOULDER
11. PLACE LT STRAP OVER SHOULDER   11. PLACE LT STRAP OVER SHOULDER
12. PLACE SH HARN TABS OVER TANG   12. PLACE SH HARN TABS OVER TANG
13. INSERT RT TANG INTO LT LATCH   13. INSERT RT TANG INTO LT LATCH
14. LOCK SEAT BELT                 14. LOCK SEAT BELT
15. ADJ LT SEAT BELT HALF          15. ADJ LT SEAT BELT HALF
16. ADJ RT SEAT BELT HALF          16. ADJ RT SEAT BELT HALF
17. ADJ LT SHOULDER HARNESS        17. ADJ LT SHOULDER HARNESS
18. ADJ RT SHOULDER HARNESS        18. ADJ RT SHOULDER HARNESS
19. REACH TO LOCK LEVER            19. REACH TO LOCK LEVER
20. GRASP LOCK LEVER               20. GRASP LOCK LEVER
21. MOVE LEVER FWD TO LOCK         21. MOVE LEVER FWD TO LOCK
22. LEAN INTO SHOULDER STRAPS      22. LEAN INTO SHOULDER STRAPS
23. RELAX PRESS AGAINST SH STRAPS  23. RELAX PRESS AGAINST SH STRAPS
24. MOVE LEVER AFT TO UNLOCK       24. MOVE LEVER AFT TO UNLOCK
25. LEAN INTO HARN TO CK UNLOCK    25. LEAN INTO HARN TO CK UNLOCK
26. RETURN TO NORMAL SITTING POS   26. RETURN TO NORMAL SITTING POS
27. REACH TO SHOULDER HARNESS      27. REACH TO SHOULDER HARNESS
28. GRASP SHOULDER HARNESS         28. GRASP SHOULDER HARNESS
29. PULL FWD RAPIDLY TO CK LOCK    29. PULL FWD RAPIDLY TO CK LOCK
30. REACH TO LOCK LEVER            30. REACH TO LOCK LEVER
31. GRASP LOCK LEVER               31. GRASP LOCK LEVER
32. CYCLE LEVER TO UNLOCK          32. CYCLE LEVER TO UNLOCK
33. LOOK TO OVERHEAD PANEL
34. VISUALLY CHECK ALL C/B IN
35. REACH TO OVERHEAD PANEL
36. RESET ANY C/B NECESSARY
37. REACH TO OVERHEAD SWITCHES
38. SET OVERHEAD SWITCHES (19)
39. SET FUEL HANDLE ON
40. OBS FREE AIR TEMPERATURE
41. CHECK FREE AIR TEMP GAGE SEC
```

Figure 3 Task Allocation Sample Data Produced by Model

Table 12-8. Scout Helicopter NBC Work Load Analysis (Before Flight)

Task	MOPP	Time (sec) Allocation	Min.	Mean	Max.	System Workload	Pilot Workload	Copilot Workload	Success Probability
Before Starting Engine 1	0	Nominal	43.50	45.06	46.70	0.96	0.96	0.63	1.00
“	2	47.00	47.50	49.25	50.90	1.05	1.05	0.69	0.00
“	3	47.00	51.30	53.91	56.20	1.15	1.15	0.69	0.00
“	4	47.00	56.40	58.27	61.00	1.24	1.24	0.81	0.00
Before Starting Engine 2	0	Nominal	47.70	48.94	50.80	0.96	0.96	0.29	1.00
“	2	51.0	52.90	54.27	55.90	1.06	1.06	0.32	0.00
“	3	51.0	56.60	58.78	60.60	1.15	1.15	0.35	0.00
“	4	51.0	62.20	64.07	66.40	1.26	1.26	0.38	0.00
Before Starting Engine 3	0	Nominal	74.30	76.21	77.70	0.98	0.98	0.10	1.00
“	2	78.0	80.40	83.08	85.60	1.07	1.06	0.11	0.00
“	3	78.0	89.30	91.04	93.10	1.17	1.17	0.12	0.00
“	4	78.0	94.80	98.58	101.30	1.26	1.26	0.13	0.00
Engine Start	0	Nominal	77.30	88.62	98.90	0.90	0.90	N/A	1.00
“	2	99.0	82.70	94.65	107.50	0.96	0.96	N/A	0.84
“	3	99.0	86.70	101.03	115.10	1.02	1.02	N/A	0.36
“	4	99.0	96.90	105.14	118.60	1.06	1.06	N/A	0.16
Engine Run-Up 1	0	Nominal	58.00	62.01	68.00	0.91	0.66	0.91	1.00
“	2	68.0	62.40	67.35	71.90	0.99	0.72	0.99	0.56
“	3	68.0	68.90	76.06	81.50	1.12	0.79	1.12	0.00
“	4	68.0	76.80	81.36	86.10	1.20	0.86	1.20	0.00
Engine Run-Up 2	0	Nominal	327.80	385.51	429.60	0.90	0.00	0.90	1.00
“	2	430.0	349.10	408.97	474.30	0.95	0.00	0.95	0.72
“	3	430.0	355.70	418.31	470.70	0.97	0.00	0.97	0.64
“	4	430.0	396.40	426.53	477.40	0.99	0.01	0.99	0.56

Table 12-9. Analyais Results of Before Flight Data
Scout Helicopter NBC Work Load Analysis (Flight)

Task	MOPP LEVEL	Time (sec) Allocation	Min.	Mean	Max.	System Work load	Pilot Work load	Copilot Work load	Success Probability
Hover Check	0	Nominal	117.20	125.13	129.50	0.97	0.97	0.17	1.00
"	2	130.0	122.80	128.57	137.30	0.99	0.99	0.19	0.64
"	3	130.0	129.60	136.18	143.10	1.05	1.05	0.20	0.04
"	4	130.0	135.10	143.87	151.90	1.11	1.11	0.22	0.00
Hover Taxi	0	Nominal	82.10	90.94	98.40	0.92	0.92	0.88	1.00
"	2	99.0	89.00	98.49	108.40	0.99	0.99	0.95	0.56
"	3	99.0	96.20	108.59	121.70	1.10	1.10	1.04	0.08
"	4	99.0	102.80	116.23	131.70	1.17	1.17	1.12	0.00
Takeoff to Terrain Flight	0	Nominal	65.20	68.79	72.00	0.96	0.96	0.06	1.00
"	2	72.0	68.10	74.74	78.70	1.04	1.04	0.06	0.16
"	3	72.0	72.50	79.59	87.80	1.11	1.11	0.07	0.00
"	4	72.0	80.00	87.73	92.20	1.22	1.22	0.07	0.00
Enroute/Cruise	0	Nominal	85.40	90.50	94.70	0.96	0.90	0.96	1.00
"	2	95.0	91.20	98.02	105.40	1.03	0.98	1.03	0.28
"	3	95.0	102.10	109.52	117.60	1.15	1.09	1.15	0.00
"	4	95.0	108.60	116.68	124.10	1.23	1.14	1.23	0.00
Arrival	0	Nominal	33.90	38.86	42.20	0.92	0.41	N/A	1.00
"	2	43.0	35.00	39.48	44.90	0.92	0.45	N/A	0.92
"	3	43.0	36.90	39.95	43.40	0.93	0.48	N/A	0.96
"	4	43.0	37.30	41.27	44.60	0.96	0.52	N/A	0.88
Engagement	0	Nominal	47.40	51.84	54.80	0.95	0.48	0.95	1.00
"	2	55.0	50.50	54.54	56.80	0.99	0.53	0.99	0.64
"	3	55.0	54.20	57.97	62.70	1.05	0.58	1.05	0.04
"	4	55.0	59.40	61.96	65.10	1.13	0.62	1.13	0.00

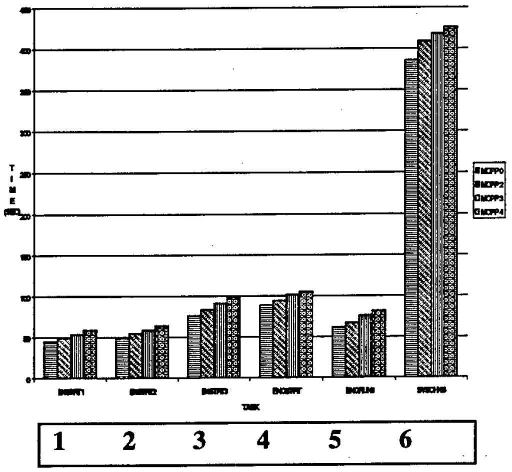

Figure 12-4. Before Flight Comparison

Figure 5 illustrates the time required comparison between MOPP levels for the tasks required to operate the aircraft in flight.

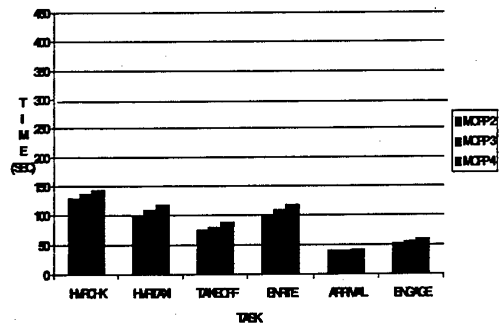

Figure 12-5. In Flight Comparison

The code identifiers are:

Hover Check: Those tasks associated with bringing the aircraft to a hover, and performing hover and pre-taxi checks.

Hover Taxi: Those tasks associated with taxi to a take off point and performing pre take off checks.

Takeoff: Those tasks associated with take-off climb and level off.

Enroute: Those tasks associated with flying the aircraft nap of the earth to an observation / attack point.

Arrival: Those tasks associated with approach to an observation / attack point and hover to attack position.

Engage: Those tasks associated with target engagement including unmasking the aircraft from an attack position and performing weapons launch. (Note; This is the one segment where the threat controls the time available when the aircraft is exposed above the protective cover of tress , terrain , etc. When wearing the NBC ensemble, the crew must sometimes modify the sequence in which tasks are performed in order not to exceed the unmasked time available.)

Figure 12-5 also illustrates the workload for each set of flying and system operations task and compares pilot and copilot workload at each MOPP level. The input data uses the MOPP level 0 as the baseline time available for each of the other MOPP levels. Any workload above 1 is excessive. Since the workload is based on the relationship Time available Vs. Time required , increasing the time available reduces the workload. It may also be noted in Table 12-9 that the probability of successfully accomplishing the task in the baseline time available approaches zero in many segments. With the exception of the engagement segment, the crew can adjust the flight regime to increase the time available with minimum adverse impact on the mission. .However, it should be noted that the time available during the attack is fixed by the threat counterattack capability and procedures must be skipped or modified to avoid excessive workload and time when wearing MOPP 3 and MOPP 4.

CONCLUSIONS:

NBC SUIT

The data indicate the present NBC suit design has a significant impact on task performance times, especially those tasks requiring overhead reach or cross cockpit reach. This can probably be attributed to the bulk or stiffness of the suit.

NBC GLOVES

The gloves contribute significantly to the increase in time required to perform in cockpit tasks. Many cockpit switches are shape coded to permit the pilot to identify the switch by approximate location and feel. This permits the aviator to manipulate the switches while looking outside and flying the aircraft. When the switch is not identifiable by location / feel, the aviator must look at the switch to locate and identify it. In addition he must carefully position he fingers to avoid inadvertent actuation of nearby switches. The model used standard MTM cases to define these actions to insure accuracy in the analysis. This causes an increase in the timeline. When operating low level or nap of the earth the in cockpit distraction could possibly affect safety.

The present gloves are very bulky and cause loss of tactile feel due to thickness. A greater number of sizes would reduce the bulkiness problem , however different material or thinner gloves are required to permit tactile feel.

MASK / HOOD

In non-NBC environments the aviator looks out the windshield while flying and glances down to see the instrument panel. Due to the mask protrusions over the nose and the lower part of the face, this is not possible with current designs. The aviator must move his head significantly downward to obtain line of sight to certain cockpit instruments or panels. This additional head movement causes an increase in the task timeline compared to non-NBC environments. The physiological stress caused by the mask is well known. The stress imposed by the mask is known to increase fatigue. Within the workload model, fatigue can be manipulated as a variable. When this is factored in all MOPP 4 task times increase by approximately 30 percent over those shown in the tables and graphs presented in this report.

RECOMMENDATIONS:

NBC SUIT

Design the suit similar to a lighter weight vapor protection similar to the one piece airforce NBC suits. A heavy pullover or jumpsuit (Possibly disposable) could be provided for operations outside the cockpit.

GLOVES:

Due to the requirement for tactile feel the gloves should be provided in the same number of sizes as the regular flying glove to reduce the bulk.. Materials should be developed (possibly impregnated GORETEX to provide tactile feel comparable or near to the existing flying glove.

MASK / HOOD:

A fully transparent face plate would be the ideal solution. A removable face plate that could be quickly donned with one hand prior to entering the contaminated area would probably reduce the fatigue factor significantly. This could permit up to a 30 percent reduction in task timelines and workload when operating MOPP 4.

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Health, Environment and Safety (HES) in Military Aviation : Implications for the RNoAF New Search And Rescue (SAR) Program

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1. Summary

The RNoAF Institute of Aviation Medicine has been involved in developing a quality control system for military aviation in order to emphasize and improve occupational health and safety in the military aviation operational environment. A new military regulation has been developed to ensure Human Factors evaluations of all new systems and aircraft. The RNoAF New Search And Rescue Program represents one of the first projects in which personell from the RNoAF Institute of Aviation Medicine have been involved as an integral part of the project process. The work was performed in close cooperation with other sections of the RNoAF, in particular the Air Material Command/Test Pilot Office and the Flight Inspectorate, together the 3 organizations were responsible for coordinating all technical, operational and human factors aspects related to the project.

The recently implemented regulation, requiring Human Factor evaluations on all new aircraft and equipment for the RNoAF, has led the way to a new and structured focus in military aviation. This focus implies not only a direction towards increased emphasis on what is viewed as the primary cause factor for aircraft accidents today, but provides a system for improving the crew's health and safety in an operational environment.

2. Introduction

The Royal Norwegian Air Force's main objective is determined partly by the country's strategic geographical position and partly by its role in the NATO alliance. Despite its small size, the RNoAF performs as diverse tasks as combat training missions, surveillance-, search and rescue-, and transport operations. In addition, Norway participates in international peace-keeping operations, requiring specific preparation and training for its involved personnel.

Considerable demands are regularly put on operational crew performance in marginal flying conditions. Given the challenges of seasonal variations, poor weather and demanding operational task requirements, the significance of an optimal working environment for the personnel is emphasized to ensure crew health and safe flight operations.

In order to understand the basis for a quality control system for occupational health and safety in RNoAF flight operations, and its role in the Search And Rescue (SAR) program, a brief description of Norway's general policy on these matters is required. In 1977 the Norwegian parliament signed a national legislation bill on occupational health and safety for its entire workforce.. This occupational safety and health legislation encompasses not only physical and toxicological factors. Human factors, ergonomics and social and organizational psychology are also important parts of the Norwegian concept of Health, Environment and Safety (HES). In 1991, further legislation was introduced by the Parliament, leaving it's country in the forefront internationally on how to optimalize working conditions. Norway became the first nation to require specific quality control systems for health, environment and safety (HES) in all organizations..

However, military aviation is exempted from this legislation.

There has been an obvious need to focus on areas that will ensure occupational health and safety for operational crewmembers in the Air Force. Human factors and ergonomics experts have been involved in problemsolving on these matters for many years, however on an ad hoc basis. This includes taking part in evaluating equipment design for survival situations, and developing training programs to prepare personnel for teamwork in flight operations. Their efforts, however, have not been managed in a structured and coordinated manner, the field of human factors often forgotten or left out partly due to a mere lack of knowledge of its existence.

For years, though, Air Force management has observed a general dissatisfaction among aircrew on the lack of coordinated information on occupational health and safety matters. Suggestions forwarded by aircrew on improvements that they find relevant in their daily work have had a tendency to " get lost " in the bureaucracy of the system. Reports tell of decreases in worker motivation and in general physical and mental well-being, partly due to a sense of " a system that won't listen ". An organizational change was needed to make information-flow and procedures for handling these issues more efficient. This work was initiated in 1996

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and a new military regulation on occupational health and safety was implemented later that same year.

3. New military regulation for Health, Environment and Safety (HES) in Norwegian military aviation.

This new RNoAF regulation defines the aviation operational working environment as "The sum of all environmental factors, both physical and psychological, which influence the safety, health and function of all aircrew members."

The regulation involves a clearer emphasis on the operational working environment, clarifies the managerial responsibilities, and provides the organizational framework of a quality control system for health, environment and safety in Norwegian military aviation.

Four main areas are described in the regulation, namely: Basic demands on the aircraft working environment, organizational structure for quality control, principles for forwarding issues, and decision responsibility. This paper will focus on the implications the regulation has had for the ongoing SAR project in the RNoAF.

The regulation states that all factors influencing safety, function and health of crewmembers shall be adequately investigated in order to not only prevent health risk, but also to optimize performance. These factors are specified and include ergonomic, psychological and organizational aspects of the working environment as well as toxicological and environmental stressors. Crash protecton and survival is also included in the regulation. The object is to facilitate constant improvement in HES matters.

4. The SAR project

4.1 Background

Following an extensive evaluation of the current SAR capability in Norway and a thorough clarification of future requirements for a SAR 24 hour readiness program, the Norwegian government decided to complement and increase the helicopter state of readiness in the busy Oslofjord region. This additional SAR unit was meant to provide all weather, all year, 24 hour assistence. It's primary missions include that of SAR, tactical transportation for the Norwegian Army, special forces support in peace time conditions as well as limited Combat SAR capability for training and evaluation purposes. Requirements on crew state of readiness as well as availability and general capacity of the aircraft itself were asssumed similar to the already existing Sea King unit.

The RNoAF Inspectorate of flying is responsible for establishing operational requirements for the new SAR program. The Air Material Command in turn is responsible for evaluating the technical aspects of the candidates in question. Historically an aquisition of new aircraft or modifications of such has been left to these two inspectorates. Until recently it was believed that a combination of technical and operational requirements was sufficient to provide a sound basis for a decision on the capabilities of a particular aircraft. As already mentioned, human factors aspects were dealt with on an ad hoc basis only. With the new regulation in place, human factors has become an integrated part of any evaluation. The section of occupational health, safety and environment at the institute of Aviation Medicine, responsible for management of the regulation was therefore invited to participate as part of the project process.

4.2 Documentation of health, environment and safety (HES) aspects

For optimal man/machine solutions in any system, it is necessary to have a thorough understanding of the operations that are planned for that system. The psychological and physiological aspects of operations must be understood in the operational context as a whole.

The HES project unit initiated the work of attaining all relevant information and available documentation on the two candidates. In addition, a major source of information lies in the operational enviroment itself. Therefore, in addition to extensive manufacturor visits and briefs, steps were taken to gather information from the operational crew operating the Sea King, Bell 412 and Lynx helicopters. Although these are non-comparable aircraft to the two candidates in the project, the man-machine interface basically deals with similar problem areas. Asking for crew's experience flying these aircraft provides a vital background for the project on the needs and requirements for functionality and safety of the crew who are expected to fly the new aircraft in due time.

A recently performed audit questionnaire among all RNoAF air crew was analysed specifically towards helicopter problems, resulting in several specific points relevant to the project.

4.3 The Human Factor evaluation

The human-machine interface in an aircraft system encompasses all aspects of an operation ; both technical and operational. The fact that the field of human factors focuses on the aviator, in turn required to perform optimally in a technically advanced environment and in an operationally complex setting , necessitated a close cooperation with both the Air Material Command and the Inspectorate of Flying.Two candidates passed initial evaluations, one American and one European candidate. Each candidate was evaluated on an array of predetermined operational, technical and human factors requirements and a common weighting and scoring system was devised to enable valid comparison.

The HF evaluation requirements were divided in the following sections and were largely based on crew feedback and research findings in the area of human factors engineering :

- Ergonomics and human/machine interface
- Software and Automation
- Cockpit environment
- Personal flight equipment

Ergonomics and human/machine interface
Displays and instrumentation were evaluated in cooperation with pilots. Focus of attention was size, placing and functionality of multifunction displays. As the Norwegian population are relatively tall, anthropometric considerations are important. Likewise, the RNoAF requires aircraft to also accomodate female crewmembers with a smaller average size.
For the pilots specifically, who are "trapped" in their seats for the entire flight, ergonomically formed seats are vital for optimal functionality.

Software and automation
Automation of crew tasking is primarily developed to reduce workload and improve situational awareness during missions and is as such a positive factor in aircraft systems. In this context automation is provided to assist the crew in prioritizing correctly in complex situations. It was considered important to put particular emphasis on the amount and degree of automation deemed necessary in the aircraft. Practical sides of this includes autopilot and flight management system functionality, autohover possibilities etc. The emphasis is on automation for workload reduction purposes, leaving important decision-making mainly to the crew.

Cockpit environment
The helicopter environment is known for the strain it poses on the crew. The physical and mental strains of vibration and noise are important to document in any evaluation of stress factors in helicopter environments. As a consequence of vibration and noise, the ergonomics of crew seats and the provision for e.g. active noise reduction devices were considered. Toxicological factors as well as crash protection and survivability were assesed relative to clearly defined requirement goals.

Personal flight equipment
Operating in often marginal weather, the SAR unit requires a crew who are prepared to survive in extreme conditions at sea, facing the obvious danger of both physical and mental trauma. Temperature control is another potential stress factor for the crew. Specifically, surviving at sea requires protection against hypothermia. Operations requiring immersion suits may result in the opposite problem of overheating. Heat-stress is well known in the helicopter environment and considered by the crew themselves as one of the most important issues to address. In addition, sustained operations that often span an 8 hour flight are known to put additional strain on the crew. An important part of an evaluation of helicopter candidates for Norwegian conditions therefore involves careful consideration of aircraft systems to ensure provisions for temperature control.

4.4 Structuring and scoring of evaluations

A set of requirements were formulated for each of the four areas previously mentioned. These requirements were formulated as either *shall* or *should*-requirements.

The *shall* requirements are points that are considered absolute. They were therefore not scored specifically. An example of a shall requirement was: "The cockpit, cabin and external lighting shall be Night Vision Goggle compatible."

Each *should* requirement was given a weighting from 1 to 3 according to a defined weighting system. An example of such a requirement was: "There should be a declutter option for multi-function displays" This requirement was weighted with 2 points.

Each *should* requirement was then evaluated giving 0, 0,5 or 1 point for non-compliance, partial-compliance or full compliance respectively.
The weighting points and the evaluation points were then multiplied to give a weighted score for each requirement.
By adding up the weighted scores for each requirement, the two helicopter candidates can be compared in a near-objective way in relation to health, environment and safety. Figure 1 shows an example of how sum scores for a set og requirements, A and B, are met.

Figure 1. Example of the weighted scoring system for health, environment and safety requirements

Candidate X :

Requirement no.	Weighting	Compliance	Weighted score
A	2	0.5	1
B	3	1	3
SUM			4

5. Discussion

As already mentioned earlier human factors has been part of the military system for years, addressing the importance of improving the workplace to ensure optimal functionality and ultimately high level performance. The problem is that these efforts have been more or less accidental and uncoordinated in nature, and as such vulnerable to budget cuts. The lack of a structural approach in human factors issues has earlier often led management to conclude that problems in this are of no major concern, merely representing an unfortunate aspect of working in a military system that the crew simply must cope with. This lack of prioritizing human factors in the military system exists despite the regular cries from the crew themselves who daily operate ergonomically poorly designed equipment and whose voices often don't reach the ears of the

decision makers. Merely because there has been no formal system to bring them forward properly.
How can we, as professionals, influence decisions to improve operational working conditions for our air crew, and thereby ever safer and more efficient flight operations? Aquisitions are obvious and important opportunities to affect the flight working environment and flight safety. New aircraft can have a life span of more than 30 years, requiring major upgrades. Therefore, decisions on new aquisitions today may affect occupational health and flight safety for decades. HES particiapation is important thruoghout the aircraft systems life span to ensure continous human factors emphasis also in upgrade phases.

Influencing aquisition as well as upgrade processes should therefore be an important part of any HES strategy. This, however, requires sound and reliable methods for documentation of facts relating to health environment and safety. To be able to do this work in a professional and reasonably objective manner, it is critical to include work on HES requirements as early as possible in an aquisition project.
This can be achieved by formalizing health environment and safety by regulation and through procedures to form a quality control system that continously seeks to monitor, audit and improve aircrew working environment.

Given the formal implementation of a quality control system for the Royal Norwegian Air Force, what does such a system mean in the long run ? What do we expect to benefit as an organization as well as for individuals ?

The long term benefits of introducing a quality control system in the RNoAF can be divided in 3 areas : benefits in structure, control and commitment and finally in decision making policies.

5.1 The benefits of structure

Health, environment and safety issues have become a priority in the RNoAF. In order to meet this goal of quality control in flight operations, relevant expertise in human factors and ergonomics must work in a coordinated and structured way. Problems encountered in the system require expertise from different professions, such as medicine, psychology, physiology, and ergonomics. Such expertise is found in the system but they do not specifically coordinate their work. The current quality control system was established to be able to meet this goal, the main purpose being to provide management with a tool to solve human factors related challenges in operational settings.

5.2 The benefits of control and commitment

According to knowledge accounted for in organizational behavior litterature, an important factor in predicting the well-being of any company, involves the level of experienced *control* and *commitment* in management as well as in personnel. By control is meant the individual's belief that he is able to influence his own life and outcome, that he is able to participate in forming his future by offering solutions to a mangement system that is developed specifically for listening to his point of view. A sense of control over own working condition by influencing its shape and quality, will in turn show in increased *identification and personal involvement* with the company. Specifically, a high degree of commitment to the company will show in acceptance of shared goals and values, a willingness to exert effort on its behalf, and last but not least, a desire to remain within the company as an active participant.

5.3 The benefits of decision making policies

The current quality control system developed for the RNoAF is first and foremost viewed as a managerial tool. By this is meant that to ensure correct decisions made by management, the new organization has been given the task of gathering information and to search for relevant documentation on human factors aspects in order to give those responsible the best possible basis for making correct decisions. In other words, they are made responsible for coordinating available expertise within the RNoAF as well as consulting external expertise when necessary on the actual topic to be able to present a scientifically sound basis for preferred improvements.

By constructing formal rules for problem solving, the frequency of ad-hoc solutions is reduced, forwarding a standardized way of handling issues and as a consequence; introduce a greater predictability in the system. *Predictability* and *standard handling procedures* for occupational health and safety issues in turn results in a work force well aware and informed of company policy, a prerequisite for developing an understanding, acceptance and confidence in leadership decisions.

6. Lessons learned

Since implementing HES in 1996, there have been several lessons learned. Introducing a modern HES concept into an already existing organisational structure has met with some, not unexpected, resistance. First of all, problems have been encountered in gaining entry to a system that appears reluctant to change preexisting, however incomplete, procedures for handling HES issues. Human factors still struggles in the shadow of traditionallly important technical and operational factors, its value often forgotten in budgetting and resource allocation.
Secondly, an important lesson learned involves the discrepancy between apparent acceptance of a quality control system among management and an understanding of its consequences. The New Search and Rescue Program for the RNoAF is as such one of the very first projects that actively considers the new

regulation and incorporates human factors as part of the total evaluation. A regulation is only useful if it is viewed as such by all parties involved.

7. Conclusion

Coordinated effort from expertise in human factors and ergonomics is needed to provide management with a tool to solve human factors related challenges in operational settings. The RNoAF New Search and Rescue Program is one of the first investment projects in Norwegian military history where expertise in human factors has contributed as an integrated part of the project process.

The new military regulation provides the structure and systematic approach that is needed to ensure continous focus on and improvement of crewmembers health and safety in their operational environment. The main benefits of such a formal system are increased emphasis on safety issues, it allows a more structured approach to risk assessment, auditing and inspection and it introduces a greater predictability and confidence in leadership decisions.

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Rotary-Wing Crew Communication Patterns Across Workload Levels

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1. SUMMARY

Human error has been identified as the primary contributor to aircraft mishaps. A critical implication of this finding for the military rotary-wing community is the need to objectively assess the coordinated behaviors of two-person aircrews. Specifically, there is a current, pressing need to gain an understanding of crew communication patterns and how those patterns are affected by the high stress, high workload environment inherent to this milieu. Two-person aircrews were presented with 402 single-engine emergencies while completing a total of 272 full-mission simulated flights at three Army posts. In addition, 11 aircrews completed a series of 10 simulated training missions requiring incrementally increasing overall workload. We used the Coordination Index Rating of Crew Linguistic Events (CIRCLE) system to analyze paired verbalizations reflecting crew coordination basic qualities across flight phases requiring varying workload levels. We developed a normative template of mean crew communication index ratings across workload levels, against which individual crews may be compared. The patterns of each of the crew coordination basic qualities across workload levels are presented. The template of crew communication patterns across workload levels developed in this study may be used to assess the effectiveness of crew communication training efforts in the future. Furthermore, this study demonstrated the ability of CIRCLE to address specific fluctuations in communication patterns, suggesting the potential utility of the system towards analysis of other factors affecting crew communications.

2. INTRODUCTION

Several investigations in the past few decades have indicated that more than 70 percent of aircraft accidents involve some sort of human error and that most of these errors stem from failures in communication, teamwork, and decision making (1). Crew communication, or the flow of information between individual operators, serves as the coupling agent that determines the functioning of the operators as an ensemble (2). In the cockpit, crew members coordinate their actions through commands, statements of intent, self-reports, acknowledgments, and questions (3), and it has been suggested that a breakdown in these communication components is the first step leading to accidents and incidents (4,5). This contention has been corroborated by several retrospective studies of commercial and military rotary-wing accidents (6).

Robert Helmreich (1) recommended that a potentially effective deterrent to aircraft mishaps would be "training focusing on the inherent limitations of human performance, including the impact of stress on the ability to absorb information and make decisions . . .". However, research has neglected to systematically examine the relationship between workload and cockpit communications, perhaps because crew coordination is dynamic and difficult to objectively quantify with a meaningful metric.

Our objective was to quantitatively assess the effects of workload levels on the coordinated verbal behaviors of two-person military aircrews.

3. METHODS

3.1 Procedures

Researchers from the U.S. Army Aeromedical Research Laboratory instructed simulator operators at three Army posts to present UH-60 aviator crews with at least one single-engine emergency during the course of their simulator session. No other specific restrictions or qualifications were imposed, therefore yielding a normative sample of self-determined two-person crews using high fidelity flight simulators for various training purposes. All sessions were videotaped and the videotapes were analyzed for crew coordination basic qualities using the CIRCLE system. Coordination Index Ratings (CIRs) were then meaned and compared across phases of flight. Expert ratings were used to quantify workload levels associated with each phase of flight, thus allowing an analysis of the effects of workload on crew communications.

3.2 Sample

A total of 272 UH-60 simulator flight videotapes were collected from three Army posts. Within these sessions, 402 single-engine emergencies were presented to subjects. Each session lasted approximately 1 to 2 hours. Phases of flight were identified as: taxi, preflight, takeoff, straight-and-level, slingload, visual flight reference (VFR), low-level, instrument meteorological conditions (IMC), contour, instrument landing system (ILS) approach-and-landing, ILS missed approach, emergency procedure, under attack, and crash.

3.3 Analysis

3.3.1 Crew Coordination

We developed and used the CIRCLE system to objectively quantify the crew coordination basic qualities demonstrated in each flight phase. CIRCLE is a comprehensive system of sequential analysis that codes all verbalizations and lack of expected verbalizations between the pilot and copilot. Codes include: Command, Question, Observation, Self-report, Acknowledgment, Reply, Zero response, and Dysfluency. Verbalizations are then paired and specific pairings are converted to indicators of eight crew coordination basic qualities listed in the Aircrew Coordination Exportable Training Package (U.S. Army Aviation Center, 1992). These include Team Relationships, Decision-Making Techniques, Prioritize Actions and Distribute Workload, Statements and Directives Clear and Concise, Situational Awareness, Decisions and Actions Communicated, Supporting Information Sought, and Supporting Information Offered. For example, a question followed by a reply is an indicator that supporting information was sought and an observation followed by an acknowledgment is an indicator that the crew was maintaining situational awareness. Following this data conversion, we calculated the

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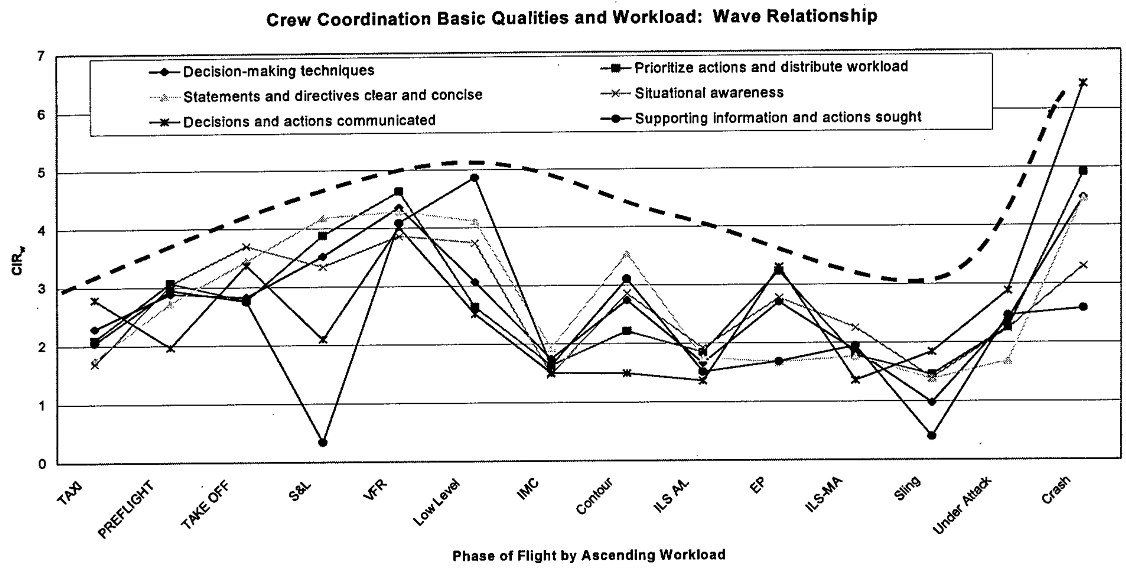

Figure 1. Crew coordination basic qualities and workload: wave relationship.

percent (CIR) of each basic quality demonstrated in each minute of each session as a fraction of the total verbal pairings in that minute. The per-minute data were then grouped into phases of flight, to yield a mean for each basic quality by phase of flight.

3.3.2 Workload

We surveyed five Army instructor pilots with a mean total flight hour experience of 4,800 hours (range: 3,800-6,000) to obtain ratings of perceived workload for each phase of flight. We used a standard 1-10 workload rating scale (1 = Very little effort/stress, 10 = Overwhelming effort/stress) and had the instructor pilots rate a wide variety of flight phases (taxi, hover check, takeoff . . .), types of flight (contour, nap of the earth (NOE), IMC . . .), tasks (mid-air refuel, emergency procedure), threat levels, and conditions (night vision goggles (NVG), over water, clouds . . .). The means of the expert ratings were used to assign a numerical workload value to each phase of flight occurring in the videotapes.

4. RESULTS

Six of the eight basic qualities demonstrated a similar relationship to workload. Decisions and Actions Communicated, Situational Awareness, Supporting Information and Actions Sought, Statements and Directives Clear and Concise, Prioritize Actions and Distribute Workload, and Decision-Making Techniques all shared a common pattern which can best be described as a wave signifying a modified Yerkes-Dodson relationship (see Figure 1). The Yerkes-Dodson Law states that performance will increase with increased workload until that workload surpasses an optimal point, at which time performance will decrease. This relationship was evident with this sample's crew communications, but with the addition of an increase in performance at extremely high workload levels, such as when crew members were under attack or about to "crash" the simulator.

Team Relationships showed a decreasing trend as workload increased, with the highest peak at "preflight". Information Offered demonstrated no appreciable difference across flight phases until peaking when crews were about to "crash" the simulator (see Figure 2).

5. CONCLUSIONS

This study generated a normative template of crew coordination across workload levels against which other samples may be compared. The pattern that emerged was a modified Yerkes-Dodson relationship for six of the qualities, which suggests that crews communicate better when moderately challenged and when experiencing extreme danger. They perform less well when faced with low workload levels (boredom) and when encountering high, but not extreme, workload levels. In addition, crews tend to focus more on establishing good team relationships when flight tasks are less challenging and to offer information more freely under the highest workload condition.

The model developed by this study is a useful tool for evaluating crew coordination performance. For example, we recently completed a crew coordination assessment for an aviation unit using the CIRCLE system. We analyzed videotapes of trainees in simulator sessions faced with higher workloads than the normative sample presented here. Their communication-by-workload patterns resembled a flattened U-shape, which was similar to the high-workload end of the wave-shaped model generated by this study. However, their CIR values were lower than this normative sample's data, so we made specific training recommendations aimed at improving the crews' communications accordingly.

This study generated a model to describe the relationship between rotary-wing aircrew communications and workload levels and further demonstrated the ability of CIRCLE to address specific fluctuations in communication patterns. Research efforts are underway to refine this model by increasing the sample size and by analyzing the data for other variables.

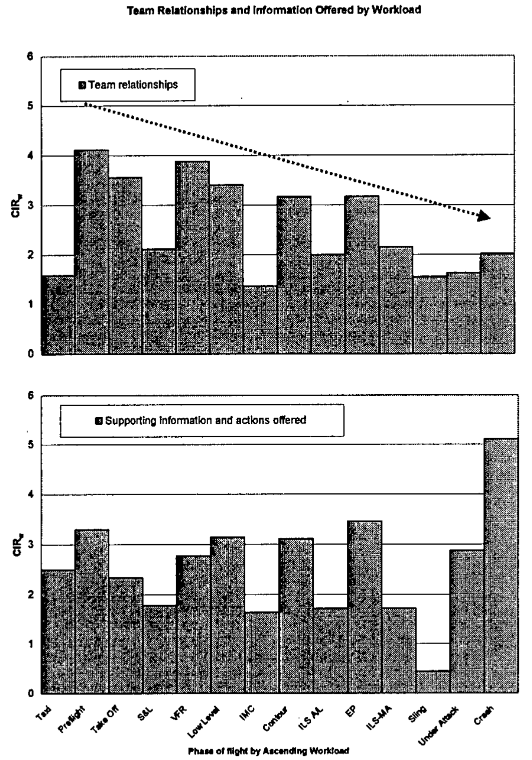

Figure 2. Team relationships and supporting information by ascending workload.

Variables such as disagreement, compliments, and humor may add to our understanding of crew communications in the rotary-wing environment. In addition, future research efforts may include using CIRCLE to assess the effects of a computer training scenario, sleep deprivation, and the use of the Communications Ear Plug on cockpit coordination. Reducing aircraft mishaps by improving crew communications must begin with the development and refinement of objective metrics for evaluating and quantitatively describing crew coordination dynamics.

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Assessment of Simulated Spatial Disorientation Scenarios in Training U.S. Army Aviators

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SUMMARY

Spatial disorientation (SD) is considered to be present when a pilot fails to perceive the position, motion, or attitude of his/her aircraft with respect to the gravitational vertical or surrounding objects [1]. The results of SD in flight may be disastrous.

The limitation of ground based training to raise the aviator's awareness of SD is widely acknowledged. A proposal was therefore raised to develop SD scenarios for presentation in a visual flight simulator.

The scenarios were developed using accident summaries from the US Army Safety Center (USASC), Fort Rucker Alabama, which were reviewed for suitable content. These were then presented as a series of scripts from which a trainer could reproduce the situation in a visual flight simulator.

The resulting scenarios were presented to 30 experienced aviators who completed questionnaire evaluations after each scenario and an overall evaluation.

The results showed a high level of acceptance of this training tool by a group of experienced aviators with differing backgrounds.

The scenarios have since been developed as a U.S. Army aviation training tool and are being distributed to units worldwide. The scenarios were developed in a UH-60 (Blackhawk) simulator, but have been refined to make them relevant to other types of helicopter operation, such as the AH64 (Apache) attack helicopter.

INTRODUCTION

SD was considered to be a significant factor in 291 (30 percent) Class A-C helicopter accidents in the U.S. Army between 1987 and 1995 [2]. The total cost of these accidents was estimated at over $486M and 110 lives were lost. These figures are the visible result of SD in aviation; the invisible effects of reduced efficiency and performance or of curtailed and abandoned missions are more difficult to quantify.

Training is one of the available approaches to the problem of SD. The aim of training in this situation is to increase the awareness of aviators to the dangers of SD, the ease with which an individual or crew can become disorientated, and to increase the reliance of aircrew on the standard recoveries from disorientating situations, such as transition to instruments or a "go around" procedure.

Training has been restricted in many situations to classroom based demonstrations reinforcing formal teaching. These often take the form of rotating chair (Barany Chair) demonstrations that highlight the unreliability of the vestibular system in providing orientation information.

In some services this is supplemented with a demonstration in the aircraft. These vary from an extended "recovery from unusual attitudes" exercise to a formal disorientation sortie flown (ideally) by a qualified flight surgeon/pilot [3] or with a flight surgeon providing physiological explanation and commentary [4]

A major disadvantage of the classroom based training is that the demonstrations lack reality, both in the illusions which can be demonstrated and because the environment of the spinning chair is so far removed from that of the helicopter cockpit. It is suggested [5] that helicopter pilots are not regularly subjected to "classical" SD illusions, but are more usually exposed to high workload, bad weather and difficult flying conditions that lead to SD. In-flight demonstrations, while extremely effective, require considerable coordination and are affected by the variability of weather. The apparent cost for this type of training is also high, though when set against the background of the current cost of disorientation accidents even a small benefit from training may be cost effective [3].

The possibility of using a visual flight simulator to address some of the training issues was investigated. The aim was to produce a series of scenarios which would demonstrate to the pilot under training the risks of SD and some of the ways in which SD can be managed as a risk in aviation. This would be achieved in the risk free environment of the simulator, with the advantages of the hold and replay facilities that a simulator offers.

METHODS

Scenario Development

The USASC at Fort Rucker, Alabama maintains a database of all U.S. Army aviation accidents. This archive was searched to obtain outline details of accidents providing illustrations of how "real world" SD accidents occur. This search produced 81 accidents in summary form.

These summaries were reviewed to select those that would produce suitable scenarios for use in a visual flight simulator.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

Accidents that were considered to be the result of careless or negligent behavior were rejected, as were those that called for information or flight characteristics which were outside the capabilities of the flight simulator. Examples of this category of scenario include those that would call for a clear view through the chin bubble of the aircraft, which is not possible in the UH60A/L simulator.

The elimination process resulted in 18 scenarios being developed for use in the simulator.

The scenarios were developed as scripts in such a way that they could be delivered in paper form with all of the information required to present the scenario in any U.S. Army visual flight simulator.

An example of a scenario is attached as Annex A to this paper. Each scenario is presented under the following headings:

Simulator Initial Conditions

The simulator operator is provided with the information required to set up the scenario, including the location, weather conditions, illumination conditions, and aircraft conditions (such as fuel states and equipment). Three of the scenarios call for the prior recording of a lead ship by the operator or instructor, details of which are included under this heading.

Scenario Development

The trainer is provided with a succinct briefing for the student that includes details of crew composition and duties, weather and task details and other details such as a tactical situation or background to the sortie. The scenario is not introduced to the student as a "spatial disorientation" exercise.

This section also contains information for the trainer and/or the simulator operator about the conduct of the sortie that is not conveyed to the student.

Debriefing

The debriefing starts with a statement that the situation just encountered was spatial disorientation and that the situation demonstrated has caused an aircraft accident. A summary of the source accident is given to the student, together with comments from the official inquiry.

A series of structured questions is included to assist the trainer to bring out the important learning points of the scenario. The debriefing may be followed, if necessary, by an opportunity to repeat the scenario to demonstrate ways of managing the individual situation using alternative flying techniques and better crew coordination, or as a demonstration flown by the trainer.

The SD Demonstration Scenario

The individual scenarios differ considerably, but each puts the trainer and student as a crew into a situation that resulted in an aircraft mishap caused by SD. In some situations the trainer is required to place the aircraft into a particular configuration, while in other scenarios the development relies upon the continuing crew coordination which allows a hazardous situation to develop. An example of this would be where the student allows the trainer to continue to fly into worsening weather until visual reference is lost completely.

The 18 scenarios are divided into the following groups:

- Day single aircraft
- Day multi-aircraft
- Night (unaided) single aircraft
- Night (aided) single aircraft
- Night (aided) multi-aircraft

Subjects

Each member of a subject group consisting of 30 experienced volunteer aviators was assigned to complete one group of six scenarios. The subject group was categorised by career group as shown in table 1. The mean age of the subjects was 35.5 years, with an age range of 25 – 61yrs.

Table 1 Subject group

Career group	Number	Mean flying hours
General Aviation	12	933
Staff Officer	6	1783
Instructor Pilot	9	5680
Medical/Research	3	667

Conduct of Trial

The 18 scenarios were divided into three groups of six for the purposes of the trial. Each group contained at least one each of day, multi-aircraft and night aided (with night vision goggles) situations. Each subject was allocated to complete one group of scenarios.

Each subject experienced the allocated six scenarios during one session. The subjects completed a questionnaire after each scenario together with overall evaluations after all six scenarios had been completed. The questionnaire is reproduced as Annex B to this paper.

The subjects also provided written comments of their overall impressions of the scenarios.

RESULTS

The results were in the form of a rating on a scale of 1-5 with 1 representing "extremely poor" and 5 representing "excellent" for the first two questions (rating the briefing and realism of the scenarios). The same rating scale was used for question 6 (rating the effectiveness of the scenario in training aviators). Questions 3-5 asked for a measure of agreement, again on a scale of 1 – 5, with the presentation of the factors that made SD worse (3), the preventive measures to avoid SD (4) and the measures to overcome SD (5). In these measures 1 represents "completely disagree" and 5 represents "completely agree."

The subjects found difficulty with question 3, so the meaning of the question was clarified for all participants. The intention of the question was to establish whether the subject agreed with the factors in the debriefing which were suggested as making SD more likely to occur.

Ratings are taken as the arithmetical mean of each group's responses to each of the questions asked. The scale of 1 to 5 is used as presented in the questionnaire. The overall ratings by career group are shown in Figure 1.

All four groups rated the scenarios above 4 (good). The lowest rating was from the group of general aviators, while the highest rating was from the Instructor Pilot group.

Figures 2–7 present the data from questions 1–6, respectively, of the questionnaire. The results are presented for each scenario, with the responses of all subject groups combined. Only one rating in the series of graphs falls below 4 (the briefing for sortie 1). All other measures are greater than 4 on the scale and the majority are above 4.5. The distribution of scores shows no scenarios scoring consistently lower scores than the group as a whole.

No individual scenario was consistently rated lower than the others, though the night scenarios, as a group, scored higher overall ratings than the day scenarios.

The answers to the open question (7) are interesting as the subjective view of individual aviators of varying experience. All comments were positive and recognized the training benefit of the scenarios. Comments included:

"This training should be added to all Army aviation training programs"

"Excellent training"

"Extremely realistic"

". . . should be implemented into initial entry rotary-wing training . . . ."

DISCUSSION

The aim of these demonstrations is to increase awareness of the risks of SD and the ways in which previous accidents have been caused. It is not the intention to train aviators to avoid specific situations or to teach avoidance or recovery maneuvers.

The obvious relevance of the scenarios by virtue of their relationship to recent accidents is thought to be a major factor in the popularity of the training. Aviators are able to relate the scenarios to everyday flying situations and they are not seen as an artificial or contrived set of situations.

The scenarios have been produced as a stand alone package [6] comprising the trainer notes for each of the 18 scenarios produced to date. It is intended that aviators will be able to experience these as part of routine flight simulator training.

It is not necessary for the pilot/student to be current on the simulated aircraft, as the actual flying and systems of the aircraft are secondary to the management of the situation.

The scenarios have also been modified to take account of the different roles of individual aircraft. Where the original scenario may call for a medical evacuation mission, this would be modified in an attack helicopter scenario to a refuel or re-arm transit flight.

It is intended that the scenarios will be refined and expanded through continued liaison between United States Army Aeromedical Research Laboratory and the U.S. Army Safety Center, thereby producing a continued flow of new scenarios highlighting the current trends in SD accidents.

A further observation of the study is that this type of scenario may be used to demonstrate the problems of poor aircrew coordination and further investigation is planned to develop these and other scenarios to assist with aircrew cockpit coordination training

CONCLUSIONS

This study has demonstrated the potential benefit of utilizing helicopter flight simulators in the process of increasing pilot awareness of the hazards of SD. The high level of acceptance and enthusiasm for the sorties by the subject group was encouraging. The scenarios are believed to be an effective training tool and were shown to be convincing and enjoyable.

From the results of this study, it was concluded that the Spatial Disorientation Awareness Training Scenarios were suitable for development and presentation as a training tool for the United States Army aviation community.

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ANNEX A
Example of a Spatial Disorientation Demonstration Scenario

SPATIAL DISORIENTATION SCENARIO #1

Simulator Initial Conditions:

The IO:
1. Selects IC#5 (TACTICAL - HARRIS FIELD).
2. Sets the visibility to 0.3 mile.
3. Requests snow conditions. (Some simulators are not capable of creating snow conditions. In such cases, dust conditions may be substituted.)

Scenario Development:

TRAINER READS TO STUDENT: Pre-mission Briefing- "You (the student) are assigned the role of PC[Pilot-in-Command] and I (the trainer) will play the role of the PI[Pilot]. Our mission is to perform hover training in snow (dust) conditions just south of the runway in South Sod. We are located at an airfield in Class D airspace. The weather is reported to be 2000 overcast with ½ sm visibility. The winds are calm. Due to the visibility and Class D airspace, a special VFR clearance will be required to operate in the South Sod. After receiving clearance, I will takeoff to a hover and hover taxi the aircraft, at 50 feet above ground level (AGL), down the length of Runway 20. At the end of the runway, I will turn to heading 190 and taxi approximately 400 meters to the field located at 21SWK1610063700." Perform before takeoff check and call for clearance.

TRAINER NOTE: The trainer establishes and maintains the aircraft in a 50 foot hover above the blowing snow. The trainer will mention seeing another aircraft in the distance and then direct the student to change the UHF radio frequency to Ground Control. While the student's attention is focused inside, the trainer begins an undetectable descent and drift to the rear. As the aircraft descends below 15 feet or when the student becomes aware of the dangerous situation, the trainer states, "I have vertigo, you have the controls!" The training flight concludes when the student recovers or crashes the simulator.

Debriefing:

1. Tell the student, "That was spatial disorientation. The situation we just experienced actually occurred and resulted in an aircraft mishap. The following is a summary of the actual spatial disorientation accident."

TRAINER READS TO STUDENT: The aircraft was at a 25 foot hover over snow-covered terrain when the PI, who was on the controls, inadvertently allowed it to descend rearward and contact the ground. The PI did not detect the drift and descent because his attention was focused on another aircraft moving to the front. The environmental conditions (fog/snow) resulted in a lack of visual cues. The PC, whose attention was focused inside, tried to take control of the aircraft, but over-controlled it by applying excessive collective. He did not have adequate time to acquire visual cues, reference points, or aircraft instrument indications. The result was that the aircraft ascended to approximately 50 feet, began a spinning descent, contacted the ground and was destroyed.

2. Ask the student:

   a. "Why did this happen?" (Solicit feedback from student.)

   b. "What factors made spatial disorientation more likely in this situation?" (The following list is not all inclusive.)

      (1) Lack of visual cues. (Blowing snow)
      (2) Perception of linear motion below threshold. (Drift too gradual to perceive)
      (3) Aircrew coordination failure. (Improperly focused attention)
      (4) Reaction was excessive. (Excessive control inputs)
      (5) Poor awareness of the risk of spatial disorientation in those flight conditions.

   c. "How could this accident be prevented?"

      (1) Use proper aircrew coordination procedures.
      (2) Perform tasks and maneuvers per the ATM [Aircrew Training Manual], applying appropriate environmental considerations.

   d. "How could this situation be overcome once you're in it?"

      By performing a go around.

3. If necessary, the trainer will demonstrate the preventive action by:

   a. Performing proper aircrew coordination.
   b. Performing proper snow hovering techniques.

4. If necessary, the trainer will demonstrate the corrective action by performing a go around per the ATM.

ANNEX B

SPATIAL DISORIENTATION POST SCENARIO QUESTIONNAIRE

Thank you for assessing the Spatial Disorientation Training Scenarios

Please answer the questions below. You may be assured that the information contained in this questionnaire will be treated with the utmost confidentiality.

******** **SD is used as an abbreviation for Spatial Disorientation** ********

Name .... Date ....

SCENARIO # ***(to be completed by simulator operator)***.. ☐

For questions 1 and 2, please rate this scenario on a scale from 1 to 5
1-Extremely poor, 2-poor, 3-adequate, 4-good, 5-excellent.

1. How would you rate the briefing on the scenario? .... ☐
2. How would you rate the realism of the scenario? .... ☐

For questions 3 through 5, please rate this scenario on a scale from 1 to 5
1-Completely disagree, 2-somewhat disagree, 3-no firm opinion, 4-somewhat agree, 5-completely agree.

3. Do you agree with the factors that made the likelihood of SD worse ? .... ☐
4. Do you agree that preventive measures would work? .... ☐
5. Do you agree that measures to overcome SD would work? .... ☐

For question 6, please rate this scenario on a scale from 1 to 5
1-Extremely poor, 2-poor, 3-adequate, 4-good, 5-excellent.

6. How do you rate the effectiveness of this scenario for training aviators? .... ☐
7. Please add any further comments on this scenario:

....

Please add any further comments to the feasibility of utilizing simulator scenarios for training aviators to avoid and overcome spatial disorientation (SD). **(To be completed once by each volunteer).**

....

Figure 4. Question 3: Do you agree with the factors that made the likelihood of SD worse?

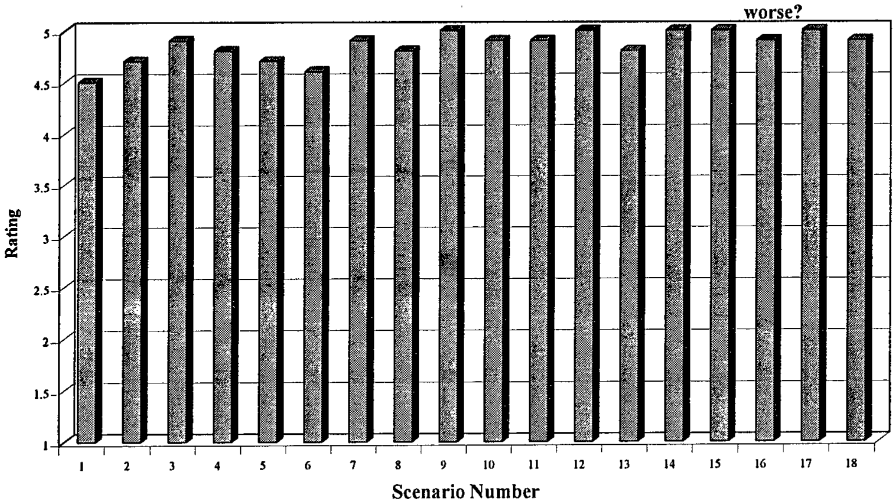


Figure 5. Question 4: Do you agree that the preventive measures would work?

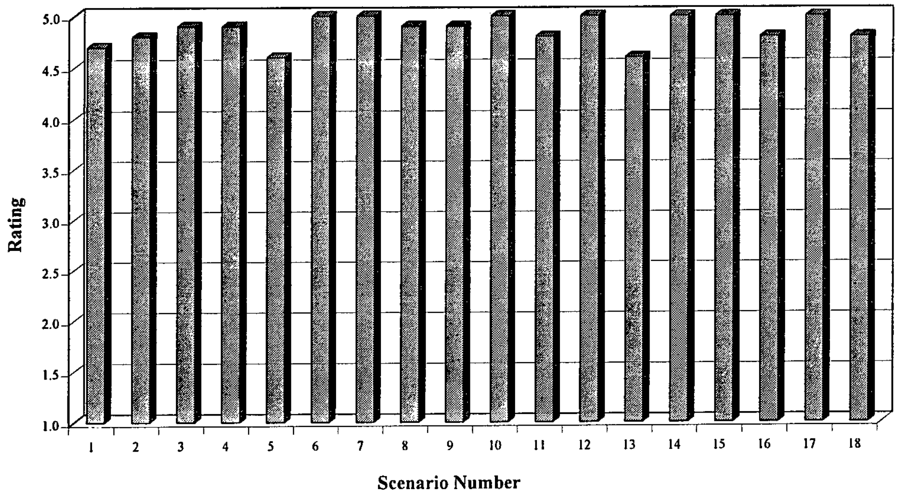


Figure 6. Question 5: Do you agree that the measures to overcome SD would work?

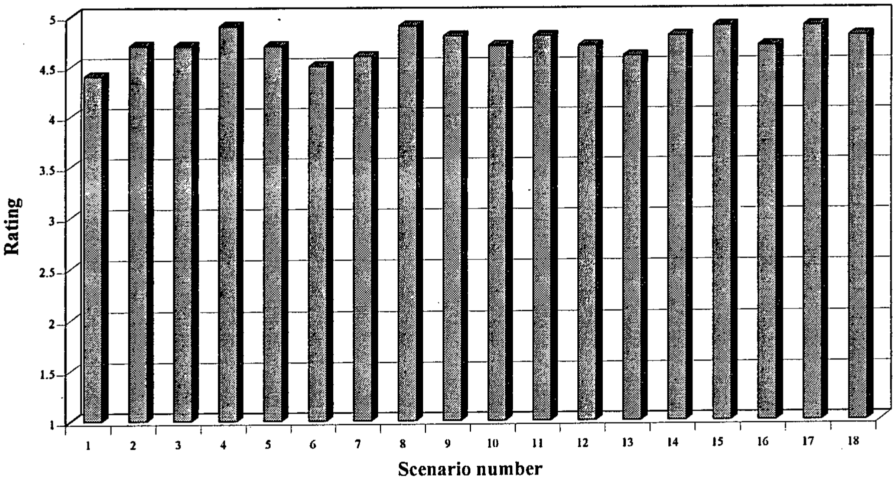


Figure 7. Question 6: How do you rate the effectiveness of this scenario for training aviators?

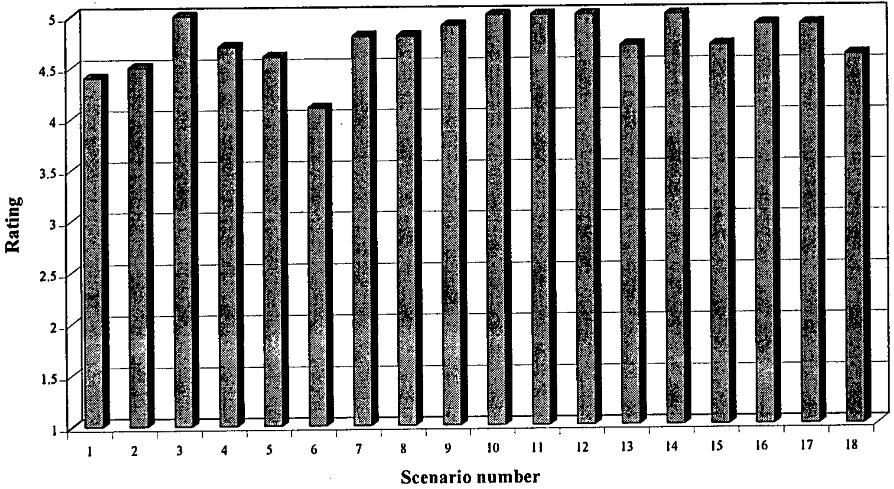


Figure 1. Overall rating by career group

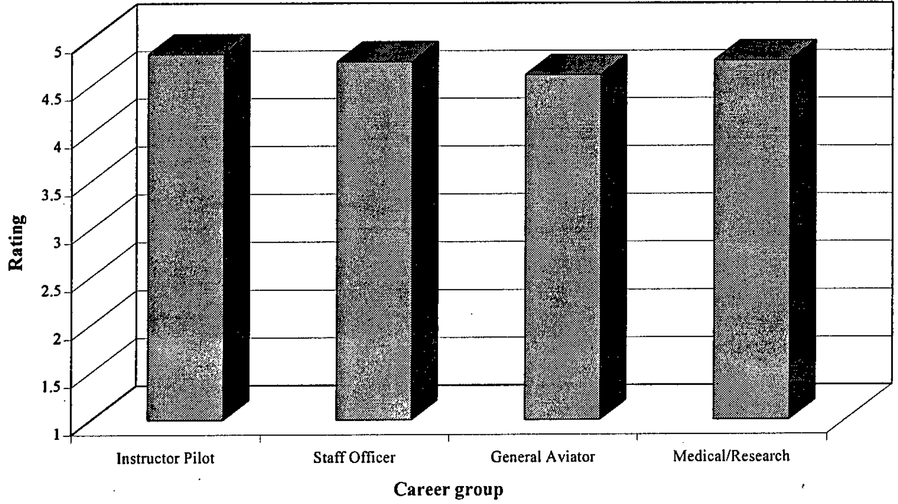


Figure 2. Question 1: How would you rate the briefing on the scenario?

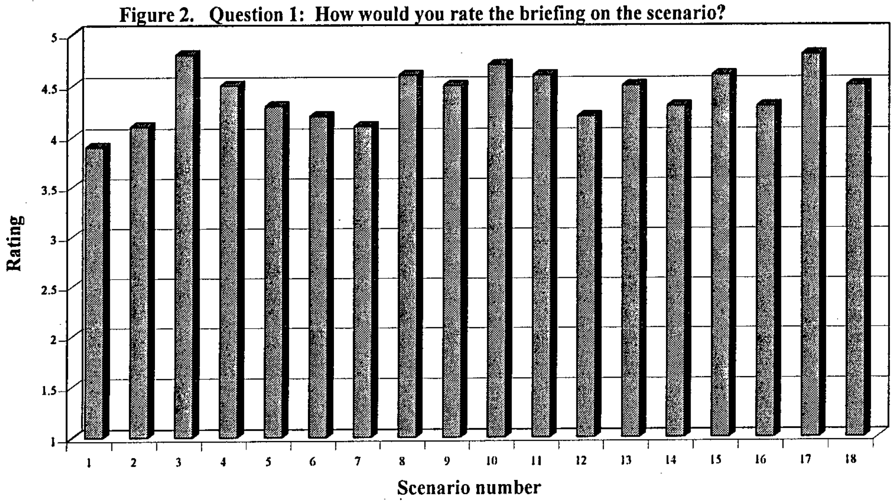
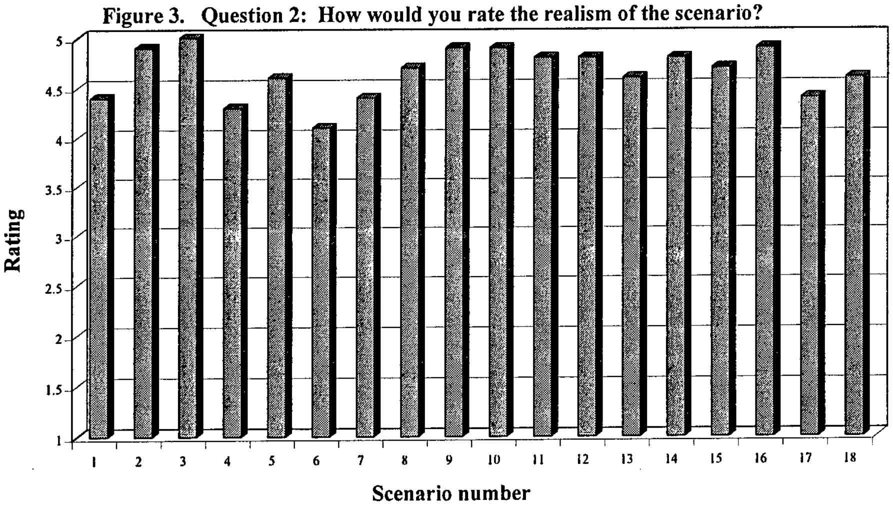


Figure 3. Question 2: How would you rate the realism of the scenario?



The Tactile Situation Awareness System in Rotary Wing Aircraft: Flight Test Results

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Summary

Loss of Situation Awareness (SA) and Spatial Disorientation (SD) contribute significantly to aviation mishaps involving rotary wing aircraft. The Tactile Situation Awareness System (TSAS) was developed to improve SA by presenting three dimensional orientation information to pilots and aircrew intuitively via somatic tactile sensory receptors. Results from simulator and flight tests have demonstrated improved SA when using TSAS and a decreased perceived workload.

Seven research pilots from the U.S. Army Aeromedical Research Laboratory and the U.S. Naval Aerospace Medical Research Laboratory performed flight tests in an U.S. Army UH-60 helicopter. The first series dealt with forward flight maneuvers including straight and level flight, standard rate turns, unusual attitude recoveries and ground controlled approaches (to minimum altitude). In this series the subject pilots wore a blackout visor to exclude any visual cues. TSAS provided aircraft pitch, roll, airspeed and heading, acquired from flight instruments, via tactile transducers (tactors) applied to the body of the pilot. The second series dealt with hover maintenance (in and out of ground effect) and transitions to and from forward flight and lateral translations. Pilots in this series wore semi-fogged spectacles to exclude external visual cues while maintaining clear view of instrument displays; TSAS provided translational velocity data.

In both test series pilots reported increased SA and decreased workload when using TSAS. TSAS improved accuracy in hovering maneuvers and forward flight. Pilots felt oriented with TSAS regardless of vestibular illusions generated during flight. Pilots reported adequate spatial orientation despite attempts to disorient them. Pilots hovering out of ground effect held position more accurately and confidently performed simulated shipboard take-off and landings without external visual cues.

TSAS can provide significant SA improvement in rotary wing aircraft while reducing pilot workload. Further development toward a deployable system is warranted.

Keywords: Situation Awareness, Spatial Disorientation, Tactile Situation Awareness System, Workload, Training, Multi-Modal Displays.

1. Introduction

1.1 The first and most reliable inflight situation awareness (SA) information display used by pilots is the visual world outside the cockpit. When outside cues are ambiguous (e.g., fog or brown out/white out conditions), the pilot must transition to visual flight instruments which accurately display the aircraft spatial orientation (SO). The U.S. Navy's Tactile Situation Awareness System (TSAS) was developed at the Naval Aerospace Medical Research Laboratory (NAMRL) in response to an alarming number of SA related military aviation mishaps [1] Even conservative estimates of loss of materiel and human resources are alarming [2] It has been noted that spatial disorientation (SD) resulting from loss of situation awareness often occurs in concert with an element of visual distraction [3]. Since present situation awareness displays in military aircraft are visual, pilots can not receive critical SA information when not looking at the display. The approach developed by the TSAS program, uses a torso suit fitted with an array of tactile transducers (tactors) that can continuously update the pilot's situation awareness in a manner analogous to normal orientation in the terrestrial environment (figure 1).

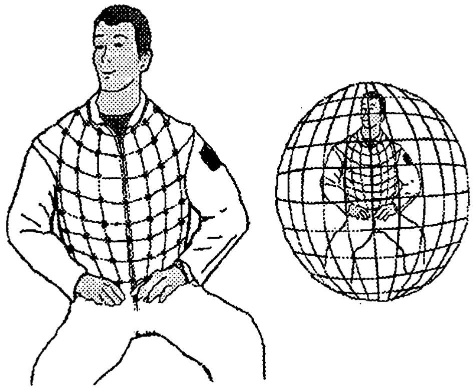

Figure 1: Three dimensional space mapped to tactors on the torso.

Objects and motion in the surrounding three-dimensional space intuitively map to specific tactor locations Using such a device, a pilot can maintain orientation information in the absence of a visual horizon or during inevitable gaze shifts from the aircraft instrument panel. Furthermore, since the

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sense of touch conveys location on the body of a tactile stimulus intuitively [4], the pilot is able to devote more time to other mission tasks that mandate visual attention.

1.2 The rationale for utilizing touch to convey position and motion perception and to overcome vestibular, visual, and auditory illusions produced by unusual acceleration environments is based largely on knowledge about the ontology of sensory development. In most vertebrates, the proprioceptive tactile system is the first sensory system to develop, followed by the vestibular system, then the auditory system, and finally the visual system [5]. In fact, the proprioceptive systems of somatosensory and vestibular function develop a rich interaction *in utero*. This follows logically since the somatosensory system needs information very early in development concerning the direction of the gravity vector in order to properly control the antigravity and gravity muscles. It is only much later in development that the auditory and visual systems are integrated into this already well-functioning proprioceptive system. The primacy of touch and somatosensation in the development of orientation behavior has been demonstrated in several neurophysiological and anatomical studies [6,7].

1.3 Present development of cockpit systems have stressed visual and auditory situation awareness instrumentation to the point of saturation. Previous tactile displays [8,9] have attempted to draw pictures or flight instruments on the body, requiring the subject to expend cognitive effort to interpret the information. TSAS, however, exploits the inherent nature of the somatic sense, which already projects to the central nervous system in three dimensions. Using TSAS, the pilot can rapidly process SA information while reducing visual workload. Since military aircraft routinely require that the pilot strap into a forward facing seat, pilot orientation in space is tightly coupled to aircraft attitude.

1.4 While the initial rotary-wing prototype originated from a design utilized in a previous fixed wing flight test [10], simulator sorties quickly demonstrated additional requirements for successful transition to helicopters. This second prototype (dubbed N-2) was modified and successfully demonstrated rotary-wing attitude control in the U. S. Army Aeromedical Research Laboratory's (USAARL) UH-60A Blackhawk (twin turbine, 14 passenger, multi-role helicopter). In 1995, the TSAS N-2 tactile interface was used to demonstrate the feasibility of a tactile display for spatial orientation in forward flight maneuvers including standard rate turns, unusual attitude recoveries and ground controlled approaches (to minimum descent height). In 1997, a TSAS version (dubbed NP-1) allowed research pilots operating the same UH-60A to perform standard hovering maneuvers in and out of ground effect and to complete simulated shipboard takeoffs and landings [11].

2. Methods

2.1 The forward flight rotary wing operations test program was conducted over a period of 3 months in late 1995. The TSAS N-2 system consisted of a 50 MHz 486 PC-compatible ruggedized palmtop computer (Badger Computer, Tampa, FL) that digitized flight instrument data provided by the onboard Airborne Instrumentation System (AIS) installed in this UH-60A research helicopter. Custom C++ software acquired the flight data and fired the appropriate tactor(s) via digital signals to driver circuitry which provided power to the electromagnetic vibrotactors. These tactors consisted of silent pager vibrotactors (Namiki Precision, Japan, 7CE-1701WL-00) mounted in custom aluminum housings. A knit Nomex/cotton garment served as a tactor locator system (TLS), supporting twelve of these tactors in an array of four columns of three tactors (three each on the front, back, left and right of the torso). This set of twelve tactors provided pitch and roll angle information. Tactor position in a particular column encoded gross ranges of angle (e.g., 1-5°, 5.0-16°, 16.0-90°). In addition, each tactor encoded three angle ranges (e.g., 1-2°, 2.0-3°, 3.0-5°) by pulsing on and off at slow, medium and fast rates (e.g., 1.4, 2.0 and 3.3 Hz). The pulsing utilized a fifty-percent duty cycle and the tactor vibrated at 90 Hz when activated. Pulsing was chosen over continuous stimulation since the pilots rapidly adapted to the constant stimulus which was soon lost in the vibration of the aircraft.

2.2 Early simulator testing demonstrated that additional information would be required to safely fly the helicopter without visual information. Barometric altitude was ruled out due to slow response characteristics. Likewise, attempts to employ the vertical speed indicator (VSI) demonstrated significant lag leading to pilot induced oscillation (PIO). Airspeed, however, responded rapidly to pitch control inputs and the combination of these two variables directly related to altitude. Utilizing airspeed error reduced PIO about a designated altitude from ±500 feet to better than ±200 feet. In order to reduce fatigue, airspeed error from a target velocity was encoded rather than absolute airspeed. This created a null point when the pilot held the airspeed within ±4 KIAS of the target.(typically 100 KIAS) A similar error driven approach, instead of absolute compass reading, was taken for heading tactor encoding. This meant that when the helicopter was straight and level, on course and at airspeed (which maintained desired altitude, given constant power settings), no tactors were firing. As the aircraft drifted or was directed away from the null condition the appropriate tactors informed the pilot of the change in state. These auxiliary channels were limited to two tactors each; airspeed located on the left arm (biceps for overspeed, wrist for underspeed), heading located lateral to each thigh. The overspeed tactor (biceps) simply pulsed at 1.4 Hz, while the underspeed (wrist) tactor pulsed at 3.3 Hz). The heading error tactors were each encoded with three angle ranges (e.g., 4-9°, 9.0-20°, 20.0-180°). Pitch, airspeed and heading could be rezeroed in flight to accommodate the changes in attitude due to power setting manipulation and changes in desired heading. Simulator testing demonstrated that confusion could arise when pitch or roll tactors fired along with the auxiliary data tactors. The former encoded absolute orientation as a flight instrument (referencing a vector pointing down to the earth's surface), while the latter encoded error about a desired setting, much like a flight director. To avoid confusion and cross talk, the auxiliary channels utilized a different type of tactor (Tactaid™, Audiological Engineering Corporation, Somerville, MA) that oscillated at 250 Hz when pulsed, providing a much different tactile sensation. The Tactaids also provided a lower amplitude stimulus, which enabled the pilot to selectively ignore them until the pitch and roll tactor information was nulled out. In a typical scenario for an unusual attitude recovery, for example, the pilot corrected roll (wings level), pitch (nose level), airspeed (and, therefore, altitude) and finished with return to base heading.

2.3 Nine flights were conducted following a preliminary hover check. The initial five flights were used for debugging the system which included improving tactor contact with the body. By the sixth flight, however, reliable tactile information permitted successful maneuvers. A number of flight maneuvers were selected to demonstrate controlled flight under TSAS without visual cues. These included straight and level flight, standard rate turns, unusual attitude recoveries and ground controlled approaches (GCA's). Two research pilots performed the described flight profiles using TSAS (one other pilot was available only for the shakedown flights). Prior to initiating a maneuver, the safety pilot confirmed clear airspace and intended demonstration task. The subject pilot then lowered the helmet mounted occlusive visor (figure 2) and confirmed receipt of controls verbally.

Figure 2: Blackout visor used in UH-60 forward flight test.

During the maneuver the subject pilot had no visual cues. In the case of the unusual attitude recoveries, the N-2 was disabled until the aircraft reached the appropriate attitude; this prevented the pilot from merely retracing the steps used to enter the unusual attitude. Later in the demonstration program, heading error cues were also given to allow return to base heading, but only activated after the pilot had regained or was approaching straight and level. Following the completion of a flight task, the subject returned control to the safety pilot and flipped up the visor for a rest until the next task.

2.4 Demonstration of TSAS in hovering operations concluded in September 1997. Four research pilots flew the USAARL UH-60A with degraded visuals, provided by semi-fogged spectacles that allowed viewing of flight instruments, but excluded external visual cues. The view out the chin bubble window was similarly occluded. A new system with greater capability was built by the TSAS team under sponsorship from the Joint Strike Fighter Program Office. The hover TSAS TLS was based on the cooling vest developed for the F-22 Raptor. This vest is a simple garment that includes an manifold and distribution matrix for low pressure air that is worn over the pilot's T-shirt, under the flight suit (figure 3)

Figure 3: F-22 cooling vest used in hover flight test.

The TSAS team integrated custom designed pneumatic tactors (Carleton Technologies, Tampa, FL) into the F-22 cooling vest (Mustang Survival, Bellingham, WA) in an array of eight columns of two. These tactors provided more flexibility in waveform, amplitude and frequency of stimulation than the previously used electromechanical tactors. In addition, using pneumatic units significantly reduced the weight of the system and eliminated the need to carry electrical signals to the body, minimizing risk of shock or excessive temperature build up. The hover flight system required the development of a pneumatic flight system (NP-1). This system utilized a ruggedized 200 MHz Pentium PC compatible computer (Kontron Elektronik, Newport Beach, CA, IP Lite) running the QNX real time operating system. The NP-1's tightly coupled global positioning system/inertial reference unit (Boeing North American, Seattle, WA, C-MIGITS-II GPS/IRU), when differential GPS corrections were applied (Starlink, Inc., Austin, TX, DNAV-212), provided accurate position and velocity data to the computer, which also acquired radar altimeter data from the AIS. Custom C++ software calculated aircraft drift velocity, determined which 45 degree sector defined by the eight tactor columns best represented the direction of the drift, and fired that column at one of three different pulse rates (e.g., 1, 4, 10 Hz) to indicate ground speed ranges (e.g., 0.2-1, 1.0-2, 2.0 or greater meters/second) . Both tactors in a column were fired simultaneously to ensure a robust stimulus that could be felt through the vibration of the hover. The null band that existed below 0.2 m/s prevented significant PIO about the hover point and was determined empirically (the system was accurate to 0.1 m/s). The base frequency for the pneumatic tactor was a fifty percent duty cycle square wave at 50 Hz. Ten sorties were completed, the first five of which were used for system evaluation and optimization. The final five flight test profiles included stationary hover in ground effect (IGE) and out of ground effect (OGE), longitudinal and lateral translations (both IGE and OGE), and simulated shipboard takeoffs and landings.

3. Results

3.1 The N-2 system demonstrated successful helicopter forward flight maneuvers under tactile instrumentation in the absence of visual cues. Even when vestibular clues were unreliable, a pilot could maintain controlled flight. By setting the angle ranges appropriately (e.g., bank angle for standard rate turn assigned to fast frequency of middle tactor), the pilots could accurately maintain flight maneuvers other than straight and level. Some auditory information was not controlled (e.g., wind noise, rotor vibration changes). Since the N2 did not encode all flight information on the TLS, the subject received some cues over the ICS deliberately (e.g., engine torques, ground controlled approaches). Tactor-body contact remained the most troublesome confound throughout the test program. Just as closing the eyes or unplugging the audio system will prevent visual or auditory information from reaching the pilot, poor tactor contact prevents effective use of the tactile display. The custom fit N-2 TLS improved the overall contact compared to previous TLS designs, but still required elastic straps to secure the tactors. Loosely fitting vibrotactors prevented the subject pilot from identifying the aircraft attitude. With the loss of a lower roll tactor, which had a tendency to pull away from the body with the subject seated, the pilot often falsely believed the aircraft was level. This mainly happened in the small angle ranges of the lower attitude tactors. Cycling through the tactors while in the aircraft, prior to take off, identified contact problems that could be fixed on the ground, and successful flights followed. An improved TLS, however was warranted.

3.2 Flight control reversal errors occurred infrequently, but were significant. Initial briefs stressed that the attitude information was an absolute indication of the direction to "down". When the heading error caused directional confusion and was switched to a relative "desired" direction indicator, some reversal errors occurred, until the pilots retrained themselves. It is interesting to note that, despite briefing the pitch and roll tactile cues as a flight instrument, nearly all of the subjects initial reaction was to interpret the system as a flight director (e.g., "It's telling me to push the stick forward").

3.3 Placement of the auxiliary tactile cues off the torso, even when utilizing different tactors, caused some difficulties. Primarily the directional confusion reported when the heading and roll indication disagreed by stimulating opposite sides of the body. In addition, an extracorporeal circular motion could be generated when heading (thigh), airspeed (arm) and roll (torso) tactors fired in an apparent sequence. Careful selection of tactor activations patterns could reduce this distracting motion illusion (perhaps requiring offset timing to account for nerve conduction velocity). A more reliable approach, however, would likely keep all tactors on the torso.

3.4 Heading control remained problematic during the demonstration, aside from misinterpretation, pilots had some difficulty picking up the signal when the other channels were active. Keeping the heading tactors off until the pilot approached straight and level flight improved ability to return to base course following unusual attitude recoveries. A smart controller system that presented multiple channels of data in the manner that pilots use them would be desirable. Such a system would automatically turn off auxiliary information as pitch and roll angles exceeded normal flight parameters. As the aircraft recovered from the unusual attitude, auxiliary channels would reactivate in sequence with the recovery to original flight path.

3.5 The NP-1 system successfully demonstrated the effectiveness of TSAS in hovering operations, and made a number of improvements over the previous N-2 TLS design. All four pilots easily performed the test maneuvers with accuracy despite the absence of external visual cues. While they had a full instrument panel available during each task, the NP-1 could deliver drift information before the pilot could sense it visually. The pilots, therefore, could null out drift tendencies before the aircraft accumulated significant displacement. The pilots could also utilize the drift ranges to perform controlled translational movements and estimate their displacement. While no positional error information was provided, the pilots could hold station over a target by correcting for drift velocity.

3.6 The combination of the F-22 cooling vest and the pneumatic tactors solved much of the tactor-body contact problem seen in earlier TLS designs. The low pressure airflow through the vest applied a slight circumferential force normal to the skin surface, enhancing tactor contact. In addition the NP-1 TLS was considerably lighter in weight than the N-2, and the evaporative cooling effect of the circulating air promoted pilot acceptance. All tactors were located on the torso for this flight test, however, the research pilots felt that some sort of radar altitude information would be useful to complete the system. Attempts to locate altitude information on the left arm (similar to the airspeed error layout in the N-2 system) or on other parts of the torso were made, but not completed in this test program.

3.7 The hover tactile display of the NP-1 delivered flight information as an instrument, not as a flight director. Some pilots' initial reactions, however, were to try to move the helicopter in the direction of the tactor. Much like the control reversal errors seen with the N-2 system, the pilots readily determined the appropriate response after two to three attempted maneuvers. The only problem with the NP-1 of note was the intermittent nature of reliable differential GPS corrections near USAARL due to the terrain. Once the flight tests moved to the flat terrain near NAMRL, no further difficulties with GPS reception occurred.

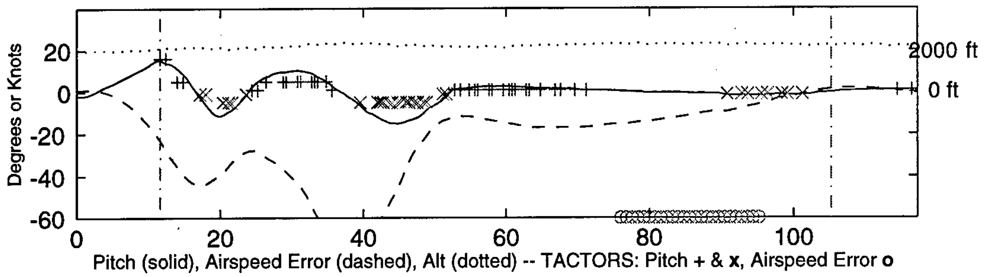
4. Discussion

4.1 Throughout the flight test programs, the subject pilots reported improved SA. Of particular note, the pilots felt that they could not become spatially disoriented while using TSAS. In order to adequately evaluate TSAS effectiveness in unusual attitude recoveries, the system was disabled while the safety pilot placed the aircraft into the starting attitude. The system was then turned on when controls were handed over to the blindfolded research pilot. If TSAS remained enabled during the entry into the unusual attitude, the pilot maintained adequate SA to make the recovery trivial. Figure 4 presents data from such a maneuver. Note that the tactors are not active until control is handed over to the research pilot (first vertical dashed line) and that the airspeed error tactors are not enabled until the aircraft returned to straight and level flight.

Unusual Attitude Recovery from 30° right roll, 15° pitch up

Vertical dotted lines indicate duration of maneuver. Time in seconds

(a) Vertical Situation Flight Parameters



(b) Horizontal Situation Flight Parameters

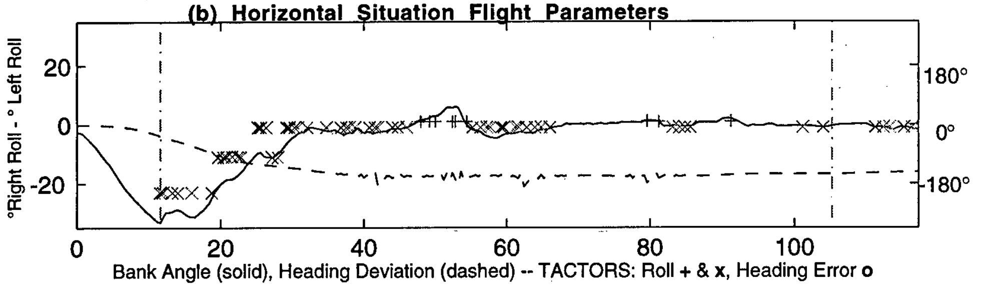


Figure 4: Flight data from spatial orientation version of TSAS. (a) Vertical situation parameters of ptich angle, airspeed error (from 100 KIAS) and barometric altitude. (b) Horizontal situation parameters of bank angle and heading deviation (±180° from desired course).+ Indicates tactor firing due to positive angle from straight and level (pitch up (a) or roll left (b)), **x** indicates tactor firing due to negative angle (pitch down (a) or right roll (b)), **o** indicates ±4 KIAS deviation from 100 KIAS (a) or direction of heading error (b). Heading error tactors disabled in this example.

4.2 The pilots using the NP-1 initially stated that they felt their performance worsened with TSAS hover holding situations, due to the amount of tactile stimulation they received. In fact, the opposite was true. Without TSAS, the pilots were unaware of slow drift and crosswinds even with unobstructed visuals. After a few maneuvers and some feedback about their performance, the pilots appreciated the accuracy of the system and how much it improved the performance of their hover maneuvers. The subject pilots commented "We could've used this in Desert Storm," or "I don't like this [with TSAS off]." One of the subject pilots, at a debrief, stated that TSAS, without any further development, would be preferable to the status quo. In addition to reporting decreased perceived workload, the pilots felt that they were able to perform maneuvers such as the simulated shipboard maneuvers more safely with TSAS. Figure 5 presents position and velocity data from a simulated shipboard landing. Of note is the overhead velocity plot. Throughout the maneuver, while using TSAS, the pilot is aware of aircraft drift and keeps it nulled except while performing the required lateral translation over to the landing zone. The same pilot demonstrates significant forward drift during the maneuver when TSAS is deactivated.

4.3 In both rotary-wing flight tests, pilot training primarily took place in the aircraft. While some simulator work was involved with the development of both programs, changes made to the system between flights meant that the pilots needed to train themselves inflight. The intuitive nature of TSAS allowed a pilot to learn and accurately perform with a novel tactile interface minutes after first experiencing it. Feedback from the safety pilot enhanced the initial learning, and the pilots rapidly reached minimal control error for each particular maneuver.

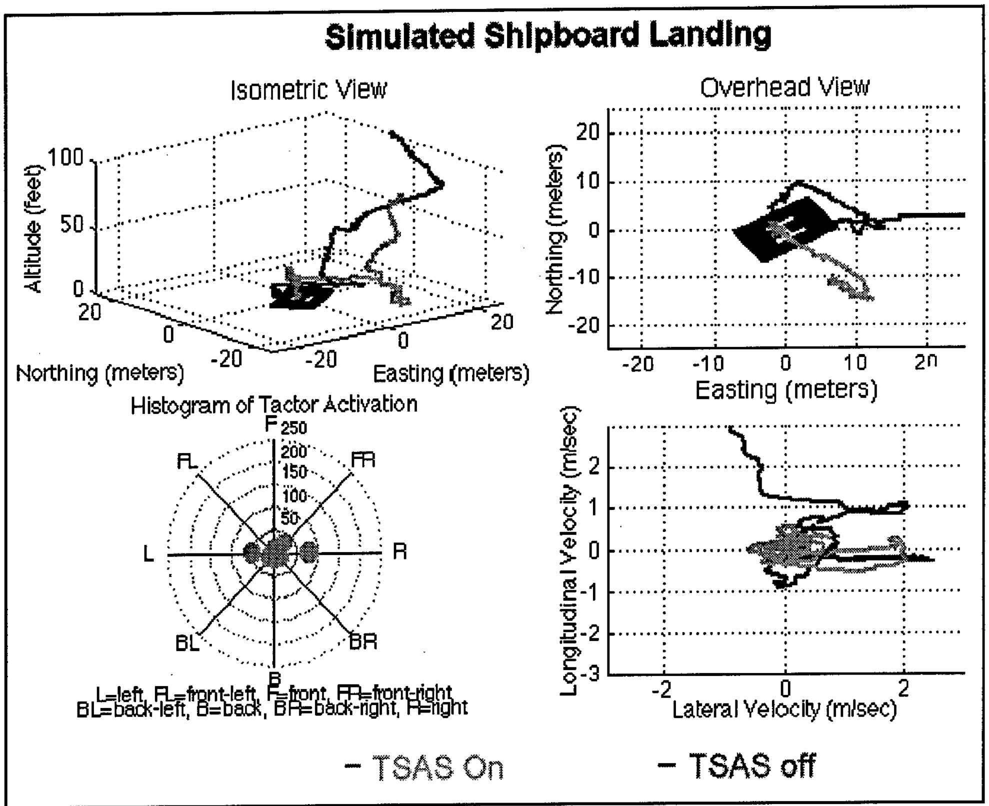


Figure 5: Simulated shipboard landing while wearing semifogged spectacles ("foggles"), with and without TSAS. Upper two plots show helicopter position, lower right plot shows helicopter drift velocity as seen from above, lower left histogram shows the frequency of each tactor's activation. Tactors appearing closer to the center of the histogram were fired less often, demonstrating less drift in those directions.

5. Conclusions

5.1 Enhanced control of forward flight and hover maneuvers, including transitions to and from forward flight has been demonstrated utilizing a tactile interface in rotary-wing aircraft. In addition, integration into a multimodal cockpit information environment has been demonstrated (audio, visual and tactile). Tactile interfaces would likely improve SA for short take off, vertical landing (STOVL) or tilt-rotor aircraft as well. Further developments should include improved tactor technology (for more discrete tactile stimuli), additional flight parameters on the tactile display (e.g., radar altitude, relative position information), threat or target directional information, and a "smart" controller to enable intelligent switching between various modes. Since loss of situation awareness contributes significantly to many aircraft mishaps, improvements such as a tactile display would reduce pilot and aircraft losses when employed. By delivering accurate tactile SA information, intuitively TSAS reduces perceived pilot workload in complex flight control regimes (e.g., vertical landings). By reducing pilot work load, sortie rate could increase, making a TSAS equipped aircraft a more potent fighting platform. The decreased workload with TSAS could also decrease training time for novice rotary-wing pilots. TSAS equipped simulators could be employed in concert with TSAS equipped airframes to simplify and shorten the amount of time required to learn to hover, decreasing cost of pilot training while improving safety.

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FEAR OF FLYING IN SPAF HELICOPTER AIRCREW

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SUMMARY

In this retrospective work we have studied Fear of Flying in a group of SPAF helicopter aircrew.We analyse the frecuency of phobia to flight,its relation with aircraft accidents and flight motivation,as well as the presence of other psychiatric diseases and therapeutic attitudes.

INTRODUCTION

Fear of flying is a disorder depicted since the begining of the Aviation, but the term was coined during the Second World War and refered to combat pilots(5).

Main feature of the disorder is anxiety or fear to flying, also fear to specific characteristics or conditions of the flight (e.g. type of aircraft, metereological conditions, high altitude) or special events such fire, ejection, physical impairment. It can appear in the middle of the aeronautical life and the pilots can't explain what is happening. The symptons are very unpleasent and perceived in a very unequal form depending on flying motivation(1,7). These situation might have undesirable consequences either at the work place or in flight safety.

The disorder can be very complex in origin(15). It is developed as an answer to cronic stress or acute stress, with a number of clinical features either psychic or somatic. It´s different to the rational fear of flying which occur in up to 20% of population(14). Fear is just an emotion against a threat or dangerous situation, which is consider as a direct hazard over the individual integrity. It's an universal way to cope with danger around us. This can arise in certain moments of the pilot carreer, such in the situation of acute onset of reality, mostly inmediatly after stressing experiences, such accidents and incidents which happen in the pilot or in his/her close enviroment (7). In order to consider this reaction or mechanism as a pathological event or disorder, it must be unpropotioned with the situation responsible of developping the reaction, without apparent reasons,out of voluntary control and to

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escape from such fearful situation(6). The DSM-IV(8) define the concept in operational terms.

In the literature we can found many pathogenics mechanisms which explain this phobic disorder in pilots and aircrew who are currently in flying status. Some are psychodinamics mechanisms, failure of coping strategies(racionalization, negative atitude), biological findings, aircrafts accidents, decrease of motivations, etc.

We have to consider that many authors and DSM-IV describes that phobic avoidance associated with the flight is not better accounted for by another mental disorder such panic disorder with agoraphobia, postraumatic stress disorder or obsessive compulsive disorder.

This work face these questions according with the review and outcome of the clinical records of a group of helicopter aircrew belongs to the Spanish Armed Forces with the diagnosis of Fear of Flying.

MATERIAL AND METHODS

This is a retrospective study where we have reviewed records from the Department of Psychiatry since 1986 with the diagnosis of Fear of Flying. Diagnostic criteria has been surveyed in each record according to the concepts expressed in this paper.

RESULTS

A total of 55 individual have been rewieved, 29 out of the 55(52.7%) were helicopter pilots and the 47.3% left mechanical engineers. Mean age were 32.9 years and the incidence of flight phobia was about 12.3%. Data regarding total number of helicopter pilots and mechanical engineers reviewed are showed in table I. Aircrews belongs to the three Services plus the Air Service of the Civil Guard.

TABLE I

- **NUMBER OF SUBJETS:**

  * Pilots: 231 (51.7%)
  * Mechanical Engineers: 215 (48.3%)
  * Total: 446

- **SAMPLE:**

  * Pilots: 29 (57.2%)
  * Mechanical Engineers: 26 (47.3%)

- **MEAN AGE:** 32,9 years

Presence of related helicopter crash was noted in 19 aircrews (34.5%). In 15 cases(27%)accident was suffered by the subject and the 4 cases left it happened in aircrews peers(see table II).

TABLE II

Aircraft Accidents Before Fear Flying Symptomatology

- YES: Own= 15 (27%)
  Others= 4 (7.5%)
  Total= 19 (34.5%)

- NO: 36 (65.5%)

Fear to flying was associated to other psychiatric disorder in 31 subjects(56.3%) with the diagnosis of minor depressive disorder(20%), adjustment disorder(12.7%) and panic disorder with or without agoraphobia(7.2%) as we can see in table III.

TABLE III

FEAR OF FLYING IN SPAF HELICOPTER AIRCREWS COMORBIDITY	
- PANIC DISORDER	3 (5.4%)
- PANIC DISORDER/ AGORAPHOBIA	1 (1.8%)
- PERSONALITY DISORDER (With anxiety)	1 (1.8%)
- POSTRAUMATIC STRESS DISORDER	2 (3.6%)
- MOTION SICKNESS	2 (3.6%)
- ORGANIC MOOD DISORDER	1 (1.8%)
- HEAD TRAUMA	3 (5.4%)
- OBSESSIVE COMPULSIVE DISORDER	1 (1.8%)
- ADJUSTMENT DISORDER (With anxiety)	7 (12.7%)
- MINOR DEPRESSIVE DISORDER (With anxiety)	11 (20%)

Good flying motivation was noted in 15 subjects (27.2%), in 24(43.6%) motivation was poor and in the rest(29%)was not clearly defined in his clinical record.

Lastly,special fearful circumstances flight related were registered:adverse metereological conditions (10.9%),flight under minimal requirements(3.6%), night flight/night vision goggles(3.6%), low level flight(3.6%), high altitude flight (1.8%), take off and landing(1.8%),mountain operation(1.8% and long haul flight(1.8%).

DISCUSSION

According to the results above mentioned the incidence was low (12.3%)and there was no significative differences between pilots and helicopter aircrew in spite of that the first have got more information about the flight desk control as well as the posibility to modify the situation. Other studies, in civilian aircrew have not got similar results (14). The cabin management and comunication between aircrew, as well as the stable work of the crews are the best explanation for it.

As we have seen before, the 29% of the sample refered some fearfull circumstances, neverthless the evolutive course of the fear got a tendency to increase, due to other circumstances flight related.

Motivation to flight is important, mostly during selection. When we consider emotional motivation(in earlier life)it is related to the need for active mastery of the environment. The cognitive root is of later origin and is based on recognition of the career, prestige,etc. The last can fail under real hazards of flight. Although,in practice,very often we found mixture of the two(7). Motivation for flying was found in 27.2%(15 subjects),but we cannot retrieved which type,but some components such presence of aircraft accident,age of aircrew,or accidents in close peers,it suggest more cognitive component than emotional one. In this study we noticed significant diferences($p<0.05$)in motivation,much more relevant in pilots.

History of aircraft accident is a reason for developping fear in 34.5% of the cases. It can depend on a classical conditioning. Such event can be more and more steady if the behaviour of the subject is to escape from it. Generaly speaking,an early behaviour therapy (systematic desensitization) can be effective(12,13).

Other pathogenetic fact can be due to an acute stress,such an aircraft accident which happened in the own subject. Fear can be hidden and asymptomatic for a certain period of time due to defense and coping mechanisms;later on the disorder itself might appear. History of accident might be significant($p<0.001$)in helicopter pilots against other aircrew members. In the case of accident in other peers,the emotional reactions in the Squadron can lead to a deeper concern of the flight risk and a more anxious state spread out. This fact plus lack of motivation will favour a fear of flying disorder(11).

Lastly,as we can see in table III, the 56.3% of the cases were diagnosticated a psychiatric and others disorders. The incidence of these findings showed no significant differences between pilots and other aircrew. In those cases we suggest three potencial situations in order to consider the sucessfull treatment:

a)Comorbidity of fear to flying and other disorder such head injury,motion sickness,organic afective disorder,personality disorder and postraumatic stress disorder.

b)The clinical course of the disorder refered to fear of flying led to other psychiatric disorder such a panic disorder.

c)A psychiatric disorder showing with symptoms such anxiety,insecurity,difficulty in decision making,decrease in cognitive capabilities, lack of control of situations flight related. All of them lead to performe the act of flying as something dangerous,with an inside unsafe feeling,risk an fear. The behaviour followed by the aircrew was evasive. It was happened in those with minor depression,adjustment disorder and panic attack with/without agoraphobia.

Treatment should be choosen considering the facts above mentioned. Ansiolitic and antidepresant are the most common biological treatment. Psychoterapy shoud be added. This is based in combined techniques such behaviour therapy,brief psychotherapy,muscle relaxion or eclectic approach(9). In other cases,rest crew is recomended,considering the type of mission(Tactic or Strategic),size of aircrew,type of aircraft and flying per month(HARTMAN and RAYMAN)(4).Neverthles,results are not satisfactory. Some authors descibes up to 47% of pilots sucessfuly treated(12). Comorbidity and lack of motivation have been associated with a bad prognosis. In our experience data shows that only 18% of the cases were reintegrated full time to the cockpit.

CONCLUSIONS

The conclusions we propose are:

First,the incidence of fear to flight was low among helicopter aircrew.

Secondly,the emotional motivation to flight in association with other ethiopatogenic factors is important. In our study,the first was much more frecuently in pilots than other crewmenbers but the incidence of flight phobia with or without other disorders was the same between pilots and helicopter aircrew.

Thirdly, history of aircraft accident was a major event found but association to other psychiatric disorders was very common, in the lasts cases,fear to flight was predominant upon others symptoms,then we suggest that is critical a complete psychiatric examination to detect mental disorders. In addition,a close clinical evolution is recomended.

Lastly,in accordance with above mentioned,there is no relation between motivation to flight and fear to flight incidence with or witout comorbidity,as well as a very few crewmenbers were reintegrated to the cockpit. Neverthless we should choose the most adecuate therapy .

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Assessment of Aircrew Stress

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1. SUMMARY

The belief systems associated with the aviator personality may not be optimal for coping with interpersonal stresses, and thus could be the target of intervention in a proactive attempt to prevent the 'failing aviator' syndrome. This study assessed members of a U.S. Army medical evacuation unit in terms of their stressors, current coping styles, thought patterns, and symptoms suggesting difficulties in coping. Respondents' perceived lack of work rewards, ongoing relational pressures, pessimism and resentment were found to be related to physical, emotional, and behavioral symptoms. This study suggests a potential preventative approach to stress management training with military aviators using cognitively oriented interventions.

2. INTRODUCTION

Psychological stress can produce pilot error. Pilot error accounts for well over half of all aviation accidents (1) and with the advent of military downsizing and related stresses (2), the military community is becoming increasingly concerned with the effects of life stress on aviator performance (3). This concern seems justified, as chronic stress factors such as pilot career strain, financial setbacks, and interpersonal problems have repeatedly been tied to aircraft mishaps (4, 5, 6).

Researchers have postulated the specific mechanism by which life stress impedes cockpit performance. When crew members are confronted by acute situational factors in the cockpit and their coping abilities are already diminished by preoccupation with external stressors, the potential for mishap is increased (7). Acknowledgment of this relationship is implied by labels such as "failing aviators" and "aviators at risk" (5), which denote crew members whose performance is adversely affected by excessive levels of psychosocial stress. Particularly at high workload phases of flight, such as approach and landing, the stressed aviator whose attentional capacities are depleted may be overwhelmed by the situational demands and prone to error.

2.1 The Aviator Personality

Personality clearly influences the way we react to interpersonal stress (8), and the typical aviator personality may not be optimal in this regard (9). Successful aviators tend to be perfectionistic, controlling, and action-oriented problem solvers (10). While these characteristics are likely to serve the aviator well in coping with cockpit requirements, they are generally associated with a fear of making mistakes, of being criticized, of lacking direct control and of being less than perfect, which may lead to difficulties in other settings and relationships (11). Exacerbating these difficulties is the tendency of aviators to deny their emotional life and to possess inadequate strategies for coping with feelings (12).

2.2 Belief Systems

Personality is also related to the quality of an individual's perception of, or beliefs about, a stressful situation (13). An aviator with perfectionistic expectations, for example, may be prone to beliefs such as "I should never make mistakes" and may thus perceive any criticism from others as extremely stressful. The likely response to cope with those feelings will be to interpret the information as incorrect ("there is no danger"), thus minimizing the stress response. This may serve a valuable purpose as a temporary coping mechanism in aviation by dampening feelings that would distract the crew member from action that is needed immediately in the service of the mission. However, in social relationships, the tendency toward denial is maladaptive because confrontation with unavoidable reality becomes more intense when it finally occurs. For example, the aviator's spouse repeatedly expresses concerns with increasing emphasis and increasing frustration as the aviator's denial continues. As the domestic stress level increases, departmentalization becomes increasingly more difficult, and the stress effects eventually invade every area of the aviator's functioning.

3. METHODS

An Army medical evacuation unit requested a stress assessment to identify relational and organizational areas to target for improvement. Based on the premise that crew members' stress may be related to the factors discussed above, we developed an evaluation to address the following questions:

1) What do aircrew members perceive as causes of stress in their lives?

2) How do aircrew members believe they currently cope with stress, and how well do their current coping techniques work?

3) What are aircrew members' thinking and feeling patterns?

4) To what degree are aircrew members hampered by physical, behavioral, or emotional symptoms that reflect chronic difficulty in managing life and work stress?

3.1 Subjects

Twenty-one volunteers from a medical evacuation unit of 34 aircrew members participated in this study. The mean age of participants was 28 (range 24-35). Nine volunteers were pilots, seven were emergency medical personnel, and five were firefighters.

3.2 Procedures

The investigator briefed crewmembers on the purposes and requirements of the assessment. After obtaining informed consent, the assessment forms were distributed to crewmembers. They were asked to complete the questionnaire independently within the following week and return the completed assessment to a lockbox located at the unit to reduce concerns about maintaining anonymity amongst coworkers. The assessment, which takes approximately one hour to complete, was administered on this single occasion. The investigator then collected the completed forms.

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Through the briefing and cover materials, crewmembers were informed that the purpose of the assessment was to identify their stressors and thereby potentially inform the investigator as to the types of services that would best meet their needs as a group. To elicit honest responses and alleviate concerns about confidentiality, crewmembers were encouraged not to provide identifying information.

3.3 The Questionnaire

A questionnaire was developed that contained 271 items, each scored on a 4-point Likert scale from *None*, *Never*, or *Not At All* (0) to *Great*, *Almost Always*, *Very Much Like Me*, or *Nearly Every Day* (3). These items made up 21 scales related to 4 components: stress causes, coping styles, belief systems, and stress symptoms (Table 1).

Scales 1-6 addressed changes, pressures, and rewards in both work and personal environments. Included were family pressures, finances, social supports, and changes and stresses related to working conditions. An example item in this area is, "Too many job tasks and responsibilities."

Questions pertaining to crewmembers' coping styles comprised scales 7-12. These included: self-care, active problem solving, support seeking, control, flexibility, and time management. These scales assessed whether current coping styles help or hinder the respondent's efforts to manage stress. An example of an item from this section is, "I anticipate and plan ahead to meet challenges."

Scales 13-18 measured patterns of thinking and feeling, which could be conceptualized as attitudes about the world or belief systems. These included: self-esteem, optimism, power, purpose, self-expression, and empathy. These were drawn from cognitive therapy and from hardiness, coherence, locus-of-control, and anger research. An example of an item from this section is, "I blame myself when things do not work out the way I expect."

Finally, scales 19-21 were derived from common stress-symptom checklists and indicated the degree to which a respondent was experiencing physical, behavioral, or emotional stress symptoms. Example items in this area are: "irritable; angry outbursts" (emotional); "withdrawing from close relationships" (behavioral), and; "muscle tension" (physical).

3.4 Data Analysis

Each subject's numerical (0-3) responses were summed for each of the 21 scales, yielding 21 scores per subject. Each of the scale scores were then categorized as one of two performance levels based on pre-established criterion cutoffs. These re-coded data were labeled Strength or Distress, to indicate the degree to which the crewmember was helped or hindered by that particular area. Performance which is in the Strength range indicates a high level of effectiveness, even when under pressure. Distress suggests severe difficulty and impaired functioning. Coding scores in this manner allowed numerically descriptive statements to be made about this unit and provided for an objective identification of areas to be targeted by stress management efforts.

The 0-3 ratings from the questionnaire were used to produce descriptive statistics. They were further analyzed using Pearson Product Moment Correlations to determine the relationships among scale scores. Significance levels were set at $p < .001$ to control for p-inflation associated with the numerous tests carried out and to highlight only the most salient relationships.

4. RESULTS

4.4 Causes of Stress

Changes in the work environment were identified as causing a disruptive degree of stress for 62 percent of the respondents. Fifty-two percent of respondents identified ongoing work relationships and situations as draining.

As a strength, most of the respondents (71 percent) perceived their personal relationships, including family and friends, as fulfilling and rewarding, with few changes in the past year (62 percent).

4.2 Coping Styles

Most of the crewmembers (67 percent) reported having their coping abilities hindered by a struggle to control situations in their lives that were beyond their control. Fifty-seven percent of respondents indicated difficulties in seeking help from others, tending instead to withdraw. About half the respondents (52 percent) reported an inability to manage their time in an organized manner.

Aiding their ability to manage stress were their tendencies to make decisions and respond in an active manner (71 percent) and their willingness to change directions when problem solving (62 percent).

4.3 Belief Systems

About half the respondents (52 percent) indicated problems with feeling helpless and incapable of fulfilling their own needs. The same percentage endorsed responses indicating a problematic level of internalizing thoughts and feelings, rather than sharing them with others.

Most of the crewmembers (71 percent) reported optimistically viewing the world with hope and finding the bright side of situations. Sixty-seven percent indicate a strong sense of worth and positive self-regard. Sixty-two percent report being motivated by a sense of meaning and accomplishment in their lives.

4.4 Symptoms

Most of the respondents indicated few stress symptoms in any of the three areas: physical, emotional, and behavioral symptoms. A case-by-case analysis revealed that 62 percent of the respondents scored in the strength range in all three areas, with the remaining 38 percent scoring in the distress range in at least one symptom area. One-third (33 percent) of

Table 1. Questionnaire components and scales.

Scale	CAUSES	Scale	COPING STYLE	Scale	BELIEFS	Scale	SYMPTOMS
1	Work changes	7	Self-care	13	Self-esteem	19	Physical
2	Work pressures	8	Active problem solving	14	Optimism	20	Behavioral
3	Work rewards	9	Support seeking	15	Power	21	Emotional
4	Personal change	10	Control	16	Purpose		
5	Personal pressures	11	Flexibility	17	Self-expression		
6	Personal rewards	12	Time management	18	Empathy		

the respondents indicated a problematic degree of behavioral symptoms, or self-defeating behaviors, that ultimately increase stress and cause further problems (see Figure 1).

The Pearson correlation coefficients of all 18 scales with the symptom scales indicated that physical symptoms were significantly negatively correlated with Optimism (r=-.72, p<.001), Power (r=-.67, p<.001), and Empathy (r=-.68, p<.001). Manifestations of chronic stress in the form of pain and illness were associated with a pessimistic outlook, feelings of helplessness and harboring resentment, blame, impatience, and anger towards others.

Behavioral symptoms were significantly correlated with Relational Pressures (r=.68, p<.001) and negatively correlated with Empathy (r=-.75, p<.001). Self-defeating behaviors were associated with perceiving personal relationships and situations as draining and harboring resentment, blame, impatience, and anger towards others.

Emotional symptoms were significantly correlated with Relational Changes (r=.70, p<.001) and Relational Pressures (r=.75, p<.001), and negatively correlated with Empathy (r=-.77, p<.001). Anxiety and depression were associated with experiencing many changes in personal relationships in the past year, perceiving personal relationships and situations as draining, and harboring resentment, blame, impatience, and anger towards others.

4.5 Interrelationships

Pearson Product Moment Correlations of all scales found that Work Pressures were significantly correlated with Relational Pressures (r=.67, p < .001). Respondents who feel that their personal relationships and situations are manageable also feel that their work situations are manageable. Those who perceive their ongoing work-related stressors as draining also feel that their personal lives are distressing.

Power was significantly correlated with Active Problem Solving (r=.69, p< .001), Time Management (r=.69, p< .001), and Optimism (r=.76, p< .001). Crew members who tap into an inner capacity to make things happen and to give and receive what they need also face problems head-on, complete achievable tasks, and reach goals with little distraction. They organize their use of time based on their priorities and demands placed on them. They have the ability to see the bright side of situations and view the future with optimism and hope. Crew members who feel helpless to meet their needs also avoid coping with problems through procrastination and postponement and lead disorganized, chaotic lives. They view the world with a pessimistic sense of futility and tend to expect the worst.

Having a sense of purpose was significantly correlated with Active Problem Solving (r=.75, p< .001), Optimism (r=.79, p<.001), and Power (r=.81, p< .001). Respondents who have a strong sense of meaning and relatedness in their lives tend to face problems by actively making decisions and taking actions that are consistent with their goals and values. They view life with optimism and feel that they have the capacity to meet their own needs through their efforts. Those who find little meaning in life and feel detached and alienated tend to avoid completing the tasks that face them. They believe themselves to be helpless and incapable of fulfilling their needs, and they view the world and the future with fatalistic pessimism.

Empathy was significantly correlated with Optimism (r=.72, p< .001), Power (r=.76, p< .001), and Purpose (r=.68, p< .001). Those with the capacity to see others' points of view and recognize others' strengths and limitations also find the good in their own life situations. They believe they have the capacity to make things happen and meet their needs, and they tend to be highly motivated by a sense of purpose, achievement, and meaning. Respondents who harbor resentment, blame, impatience, and anger towards others view the world as gloomy and futile. They feel helpless and find little meaning in life.

5. DISCUSSION

The outcome of this assessment is meant to be primarily descriptive, with statistical tests having been carried out to highlight significant relationships between crew members' stressors, how they perceive and cope with them, and what effect they have on their lives. Most importantly, the data derived from this assessment were designed to elicit specific, practical recommendations for unit command to help crew members begin to manage their stress more effectively.

The most problematic causes of stress for the members of this unit were recent changes in the work environment and ongoing work-related pressures. Respondents also indicated an abundance of work pressures (i.e., on-the-job relationships, situations, or issues) that crew members perceived as constraining, difficult, or draining. Recommendations to the command included scheduling periods of rest and renewal and alleviating some ongoing stressors by having members identify the work pressures they perceived as most stressful and examining the identified areas to find any parts of the pressures that could be changed. This recommendation resulted in the command offering crew members more input, freedom, and flexibility.

The primary hindrance to crew members' ability to cope with stress was their ongoing struggle to control the uncontrollable. This finding was consistent with the literature pertaining to the "aviator personality," which stresses that the need to control one's environment may be beneficial in the cockpit, but disruptive in other areas of life (14). Recommendations in this area included teaching crewmembers to recognize "ceaseless striving" responses and to identify aspects of situations that can be controlled. Following this assessment, the principal investigator led a day-long seminar focusing on the exploration of ways to plan for frustrating situations, manage time optimally, set realistic goals, and ask for help when needed.

Respondents indicated struggling with feeling helpless or powerless to fulfill their own needs. Viewing this in light of their primary sources of stress, this finding may indicate a sense that their work-related changes and pressures were out of their control. In addition, they reported an unwillingness to share their thoughts and feelings with others, tending to internalize or ignore their emotions and beliefs. Recommendations to command included helping crew members to take control of the controllable by taking action to change aspects of situations that are within their control. For example, being involved in an intense medical evacuation unit may seem unavoidably stressful by nature. However, members can help manage their individual stress levels by maintaining good health practices and rest, avoiding alcohol, getting involved in family-oriented recreational activities, communicating needs and grievances, etc. The principal investigator presented a unit-wide family seminar designed to teach crew members and their spouses to communicate in effective, direct ways, which minimize the fear of vulnerability.

6. CONCLUSIONS

This study served to establish the viability and utility of this assessment device for military aviation units. The individualized results suggest the potential for directing intervention measures to the specific area in need of attention to manage the stress of members of a particular unit. Yet to be undertaken are outcome studies demonstrating the ultimate ability of the assessment and ensuing intervention efforts toward reducing the stress levels and improving the coping skills of respondents. In addition, using this assessment with various units with differing missions might reveal certain commonalties and patterns, potentially precipitating the development of standard mission-oriented stress management programs. In this way, stress management interventions would be mission-relevant. This could theoretically help to reduce resistance and increase the direct relevance of efforts to improving operational readiness. The present study constitutes an initial step in this direction.

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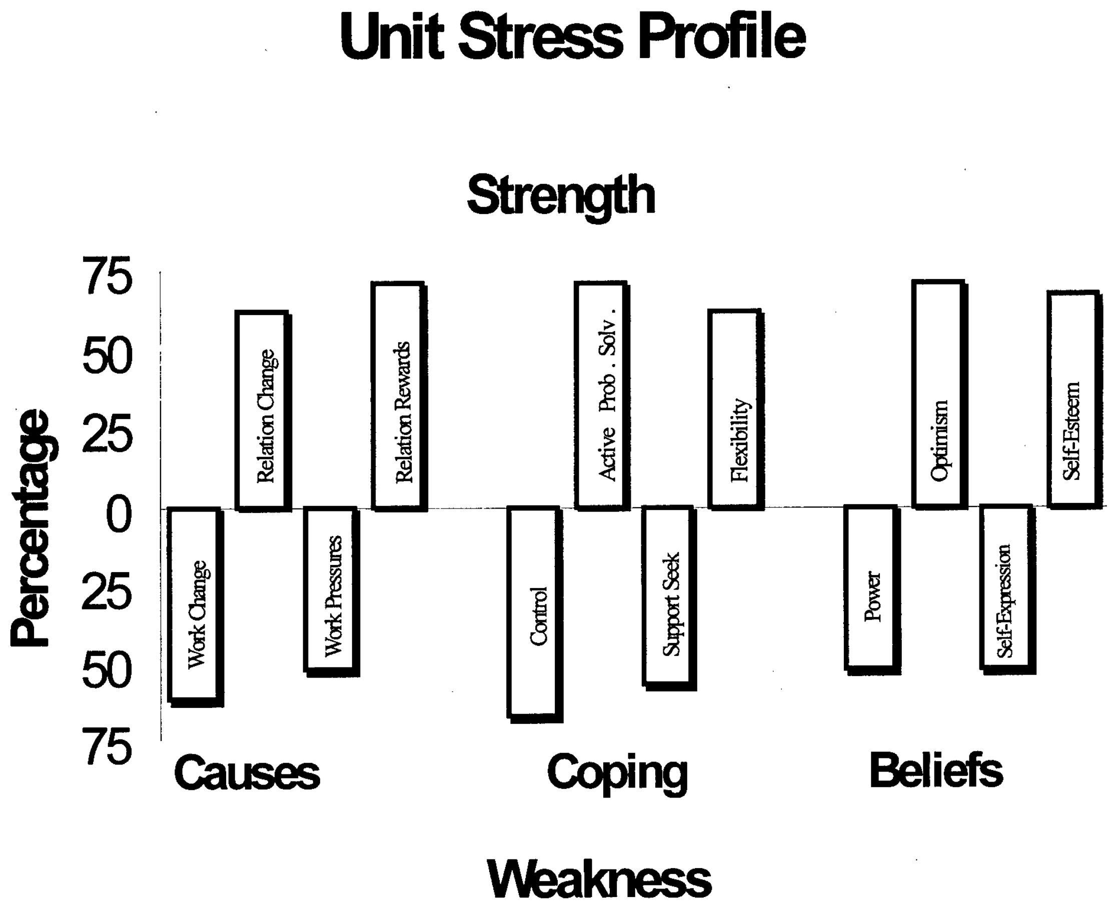

Figure 1. Unit stress profile showing results of the questionnaire.

Safety of Flight and Anthropometry in United States Navy Aircraft

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The US Navy initiated a tri-service effort in 1994 to standardize methods, agree on a population data set representative of the future Department of Defense aviator pool, and map current Navy aircraft cockpits to evaluate crew member accommodation. The Joint Primary Air Training System (JPATS) aircraft was specified to accommodate a much wider range of pilot body sizes than any other aircraft in USN/USAF history. The expansion of sizes was in both larger and smaller cockpit critical anthropometric dimensions. Because of the JPATS accommodation implications, initial USN emphasis was directed at the most critical aircraft deemed fighters. USN anticipated a concern for this expanded range of pilots to safely fly these aircraft and a need to re-engineer those aircraft to better meet a Congressional mandate for female accommodation.

To address this safety concern the USN initiated the cockpit mapping effort to quantify safe pilot fit in all operational aircraft. USN performs three dimensional computer aided drafting (3D CAD) based cockpit measurements of the accommodation provided by aircraft and measures the clearances, reaches, and field of view for a range of individuals. The end products are:

1) Prediction equations that are used to determine a percentage of a target population that can be expected to be accommodated in a particular aircraft or aircraft pipeline.

2) Aircrew candidate selections for pipeline assignments based on achieving a suitable seat position.

BACKGROUND

Naval Air Warfare Center-Aircraft Division (NAWCAD Code AIR 4.6) performed a baseline accommodation assessment of in-service Naval aircraft, including the T-34C (primary trainer), and the TH-57C, SH-60 series, and AH-1W helicopters. The purpose of the sponsored program was focused on re-engineering issues for increased accommodation provisions in all USN aircraft. The methods used in the program approach were different than procedures historically used during the aircraft procurement process and different than the current USN aviator suitability screening process. Accommodation criteria contained in the Detail Specifications for procurement of Naval aircraft have historically called for accommodation of individuals in the 5th to 95th or 3rd to 98th percentile ranges (1). The current USN screening process uses a set of anthropometric restriction codes (ARCs) (2,3). A multivariate statistical approach in determining regression equations was used to define accommodation criteria.

Due to this on-going AIR 4.6 effort and operating squadron requests for information, messages related to hazard reports were generated (4,5). In the case of the H-60 aircraft, no official ARCs were available. This was in part due to a cancellation of an instruction which delegated responsibility for developing the ARCs (6). ARCs cited here were developed from the aircrew accommodation analyses conducted by NAWCAD 4.6. These revised ARCs define the range of acceptable aircrew anthropometric dimensions that must be satisfied to achieve safety of flight and mission effectiveness in the T-34C (primary trainer), and TH-57C, SH-60 series, and AH-1W helicopters (7).

Military aircraft prior to the Joint Primary Aircraft Training System (JPATS) have traditionally been designed to the anthropometric parameters of only male aviators based on one body dimension at a time. Crew systems engineers have sought to devise design criteria alleviating most of the conflicting cockpit geometry and aviator anthropometric restrictions. Multivariate cockpit accommodation criteria require accommodation in all dimensions concurrent with any one single seat position so that an aviator can: see effectively outside the aircraft, reach and operate crucial controls under appropriate harness locked conditions, and fit the crew station design envelope.

A multivariate approach imposes more restrictive population limits than a univariate approach to better ensure a percentage of a target population is indeed accommodated for all anthropometric variables collectively. But univariate criteria can

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also be less accommodating than expected. When 95% (3rd through 98th percentile) accommodation is specified on a univariate basis, only five percent of the population is intended to be excluded by design. However, the 5% of the population excluded by the second and subsequent dimensions might not consist of the same people. As each additional dimension is stacked on to this filtering process, greater proportions of the population become excluded (8).

SCOPE OF TESTS

Evaluations of aircrew anthropometric accommodation in T-34C, TH-57C, SH-60F and AH-1W aircraft were conducted at NAS Patuxent River, MD. Each of the evaluations typically required thirty hours of ground tests conducted over a three-day period. Subsequent ground tests for data verification were conducted at NAS Pensacola, FL, and at NAS Patuxent River, MD. Aircrew accommodation data were collected in both crew stations with test subjects attired in the full complement of summer flight gear as specified for each aircraft (9). Evaluation of aircrew anthropometric accommodation included the following five functional parameters:

a. External field of view (EFOV).
b. Functional arm reach (operation of critical flight and time-critical emergency controls).
c. Functional leg reach (operation of pedals).
d. Cockpit volume clearances, including ejection clearances (where applicable).
e. Overhead/canopy clearance.

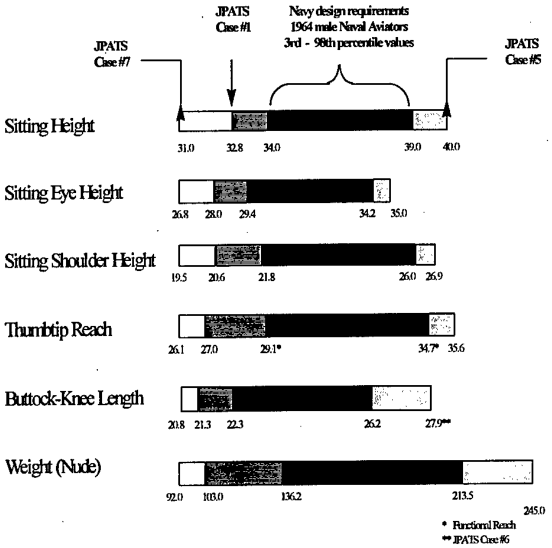
This evaluation did not address either additional accommodation limitations due to the effects of flying aggressive flight profiles, or any limitations based on individual aircrew strength. Inasmuch as the methods employed in this accommodation study differ from those utilized during aircraft design and development, the results herein reported do not imply any deficiency with respect to specification compliance by either the airframe contractor or the procuring agency.

METHOD

GENERAL

A pool of ten test subjects, representing the range of candidate aviator anthropometric characteristics (Figure 1), were measured in accordance with established methods (10). Crew station geometry and subject accommodation data were collected using developed procedures (11). The basic manual data collection procedures (11) were automated by use of a portable Coordinate Measurement Machine (CMM). The CMM, in addition to providing precise data collection, afforded digital storage of test data, and allowed downloading of data to appropriate software programs for data reduction and analysis.

Figure 1



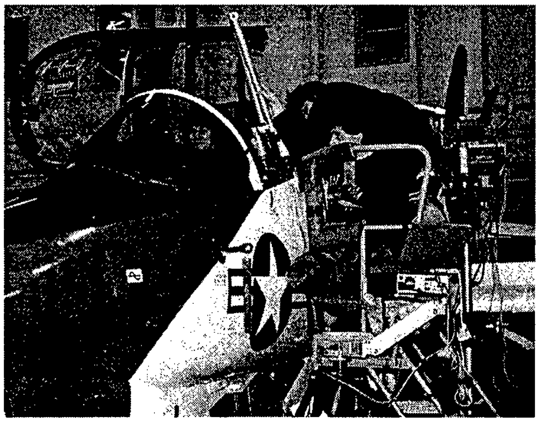
DATA COLLECTION

Drawings of the cockpit, including NATOPS pull-outs, are used to identify the location of controls and clearance issues. Blue print diagrams identify the aircraft coordinate system. These data are used in conjunction to establish an aligned cockpit geometry CAD drawing. This effort involves using the CMM. The CMM takes data such as points, lines, and planes in a 3D drawing, and saves this drawing as an AutoCad file. All prescribed hand operated controls, pedals, glare shield lines, overhead obstructions, and the knee cut-outs on the instrument panel are digitized into this CAD file.

A minimum of ten subjects are brought to the aircraft after the initial cockpit geometry has been taken. The subjects represent the extremes of the JPATS specification accommodation cases (Figure 1). Each subject is evaluated in four seat positions ranging from full up to full down in the SH-60 series cockpits (Fore/Aft, Left/Right). The T-34C and AH-1W rear cockpit have vertical adjustment only. On these one axis seats, there were four vertical adjustment evaluation intervals. Both the

TH-57C and AH-1W forward cockpit seats are non-moveable. This cockpit mapping evaluation is also performed using the CMM. A platform specific AnthroCAM computer routine is developed. Data was taken in the form of a subject's miss/over reach, and clearance distances. Specific measurement criteria were as follows:

- Clearance measurements were taken (head stationary and upright) between the top of the helmet and the overhead/canopy surface or the canopy breakers in aircraft so equipped. The independent anthropometric variable for the equation is sitting height (SH).
- Lower leg clearance distances were measured between the shin line and the line along the lower edge of the main instrument panel. The independent anthropometric variable for the equation is buttock knee length (BKL).
- Rudder control capability was measured between the sole of the individual's boot and a nominal location of the rudders adjustment range. The independent variable for the equation is functional leg length (FLL).
- The ability of each subject to reach and operate the control stick or most remote essential or emergency control in each crew station was evaluated. Functional reach was evaluated in the Zone 2 condition (shoulder harness locked with maximal stretching of arm and shoulder). Sitting acromial (shoulder) height plus seat adjustment height established the discrete shoulder position of each subject as the origin of functional reach. The independent anthropometric variables for the equation are functional reach (FR) and sitting shoulder height (SAH).
- Vertical field of view was evaluated by determining whether the subject could establish a horizontal vision line through the design eye point (DEP). The independent variable for the equation is sitting eye height (SEH).



Multivariate regression analysis is performed and accommodation prediction equations are produced where:

<u>Dependent variable</u> = miss/over reach or clearance distance

<u>Independent variables</u> = subjects' anthropometric measurements and recorded seat positions

The data generated by the routine is then organized into a MS Excel worksheet. The data is reduced into accommodation prediction equations using Statistica and additional outlier analyses. The final accommodation prediction equations are entered into a software package which delivers the predicted available seat adjustment range available for the individual anthropometric dimension inputs. A percentage of the JPATS population is expressed by dividing the successful number of accommodation values by the total number of individuals in the JPATS population data set.

RESULTS AND EVALUATION

ANALYSIS

This analysis was based on an expanded range of anthropometric measurements more accurately reflecting the current candidate aviator population. Analyses of the accommodation data collected in each aircraft yields sets of regression equations for each anthropometric dimension. These regression equations are then employed to determine fit/no-fit ranges for each anthropometric dimension in each aircraft. The fit/no-fit ranges were then mapped to the ARC domain using the relationships shown in Table 1.

Table 1

CODE	SH	FR	BKL	FLL
9	40.0-41.0	</= 27.9	> 28.0	49.0-50.0
8	39.5-39.9	28.0-28.4	27.0-28.0	48.0-48.9
7	39.0-39.4	28.5-28.9	26.5-26.9	47.0-47.9
6	38.5-38.9	29.0-29.4	26.0-26.4	46.0-46.9
5	38.0-38.4	29.5-30.4	25.5-25.9	45.0-45.9
4	35.0-37.9	30.5-30.9	25.0-25.4	43.0-44.9
3	34.0-34.9	31.0-31.4	24.0-24.9	40.0-42.9
2	33.0-33.9	31.5-32.4	23.0-23.9	39.0-39.9
1	32.5-32.9	32.5-33.9	22.0-22.9	38.0-38.9
0	32.0-32.4	>/=34.0	</=21.9	36.0-37.9

The regression equations exhibited coefficients of determination (R^2) of 0.7 or better. Uncertainty introduced by the standard error associated with each regression equation was accounted for by the inclusion of a fit check range. The revised ARCs, derived as described above for the T-34C primary trainer, and the TH-57C, H-60 and AH-1W helicopters, are presented in Table 2. Those codes listed within parentheses indicate personnel with specific dimensions that require a fit check. Codes not contained between a set of parentheses should not be assigned for flight duty in the corresponding aircraft.

Table 2

	SH	FR	BKL	FLL
TH-57 Right and Left	(0-1) (7-9)		9 (8)	(0) (9)
SH-60 Right and Left		7-9 (6) * fire T handles	0 (1-2)	0-2 (3)
T-34 Front			9 (8)	(9)
T-34 Rear	(0)		(9)	(9)
AH-1W Front	(7-9)			
AH-1W Rear	0-3 (4)			

4.6 recommended revisions to instructions (2, 3) to reflect the aircraft restriction codes contained in Table 2. With regard to references (4, 5), it is also recommended that Table 2 eliminate the open ended dimensions and cap all codes 0 and all codes 9 as absolute boundaries. Finally, recommended the CH-46, CH-53, UH-1N helicopters, and V-22 tilt rotor craft be completed as soon as practicable.

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LOW BACK PAIN IN HELICOPTER PILOTS.

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INTRODUCTION.

Back pain is a widespread problem among industrialized countries. Incidence of back pain is between 60 and 80%. Prevalence rate does not exceed 35% of the general population (1).

Aufret and Villefond determined that back pain is twice more frequent in helicopter pilots than in the general population (19).

Many papers reported prevalence rates in excess of 50%, many reported prevalence exceeding 75% (3), and pain in the lumbar area is the most common experienced by the pilots.

Most of these studies have been made through questionnaires purely subjective in regards of data collection, performed in the aircrews immediately after flight (4,5,6,7,8,9,10,11). One of these papers, performed in the Fuerzas Aeromóviles del Ejército de Tierra (F.A.M.E.T.) showed figures up to 78% of pain related to helicopter flying activities and 60% of the total number referred to lumbar area (7).

Fitzgerald et al (12) stated that, among military helicopters aircrew world-wide, backache is perceived as so common that the majority of sufferers accept it as an occupational nuisance an rarely seek medical advise by the flight surgeon.

Pain appears during or immediately after the flight. It could be transient and last for less than 24 hours, moderate in intensity, dull, localized in the lumbar area and buttocks and without irradiation (3,4,6,7,11,13,14). But there are many other aircrews who do not refer pain with such characteristics, symptoms are more frequent, persist for more than 48 hours, intensity is greater and it is associated to paresthesias of the lower extremities due to nerve compression (1 1,14)

From this perspective we can differentiate two types of pain features in helicopter pilots:
a. Pain lasts for less than 24 hours: transient.
b. Pain lasts for more than 48 hours: persistent.

Two main facts are directly responsible of back pain in helicopter crewmembers, one is the exposure to vibration and the other is poor posture (4,12,15,16).

Vibration consists of a series of displacements of a mass in both directions from its equilibrium point. These displacements are characterized by their frequency, amplitude and velocity (2). The frequencies of vibrations recorded in helicopters are between 2 and 20 Hz (16).

These vibrations are transmitted to the pilot through an undampened seat, which amplifies them. Physiological effects of vibration are caused by the deformations and displacements to which organs or tissues are subjected at certain frequencies (16). The tolerance of standing or sitting subject is at a minimum between 4 and 8 Hz. Unfortunately it is at these frequencies that the majority of vibrations in flight occur (2). But there is no good evidence that vibration forces are responsible directly for low back pain, since neither study could separate them from other associated stresses.

Shanahan and Reading (3) studied 11 pilots in a mock-up of UH-1H helicopter. Each pilot was subjected to two hours test periods; one with simulated helicopter vibration and one without. The experimental conditions produced back pain in all subjects, which they described as identical to the pain they typically experience while flying helicopters Furthermore, there were no significant differences in the time of onset or the intensity of pain for the vibration and no vibration test condition.

However, even vibration plays a very small role in the etiology of the acute back pain, authors like Aufret and Viellefond (2) speculated that repeated exposures to such conditions cause microtrauma to the spine, the exposure to vibration can lead over the long term to fractures of the thoracic spine or to herniation of the lumbar discs.

The second factor is consider the major agent causing back pain. The seat and control configuration in most helicopters, force the pilot to assume an asymmetrical posture for extended periods of time

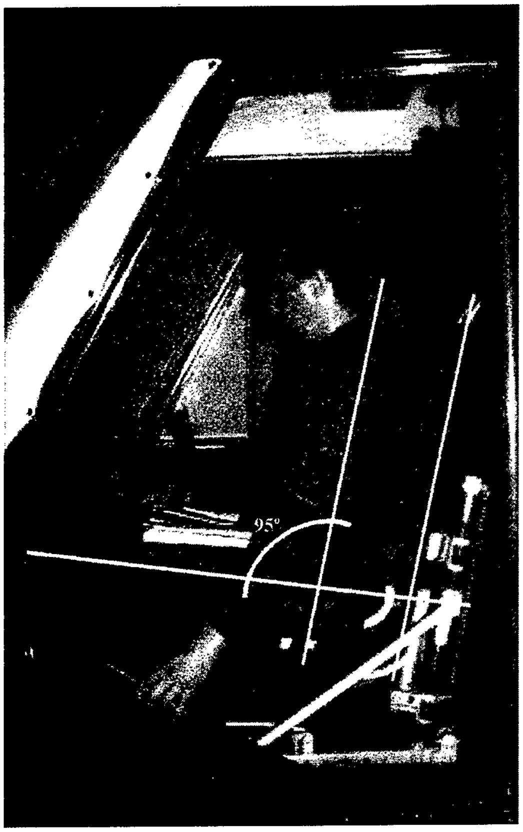
The right hand operates the cyclic pitch control, situated between the legs, and the left hand operates the collective pitch lever in the left side of the seat (16). So, while the pilot keeps his hands on the controls, the body will be bend to the left, and the requirements of flight visibility will necessitate forward flexion of the trunk, the back will not be firmly held against the seat back (Figure 1). In addition, the trunk-thigh angle in this posture is less than 105 degrees, Wisner established that this angle, in a individual seat, might be 135 degrees for a good relaxation of opposite muscle group, which is the physiological equivalent to the subjective notion of comfort (17)

Froom et al. (4) made an interesting work to prove that poor posture in flight is an important factor in the etiology of low back pain.

They studied 18 pilots of the AH-1S helicopter flying alternately in the gunner's seat, where they maintain a vertical sitting and in the pilot's seat, where they lean forward and to the left in order to operate the controls. The intensity of the back pain was great and the onset was quicker in the pilot's seat than in the gunner's position.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

Figure 1. Pilot's position in the cockpit.



The constantly maintained asymmetrical position does not permit relaxation of the spinal musculature (18), this situation probably leads to spasm of paraspinous musculature, which become fatigued, and the resultant is a straightening of the normal lumbar lordosis (19).

The spine losses the normal curve, the vertebral bodies tend to be closer together in front, and an increase in hydraulic pressure develops in the anterior part of the intervertebral discs. The nucleus pulpous is displaced towards the rear of the intervertebral space where it can irritate the nerve roots with which it comes into contact. Furthermore this flattens the lumbar curve leads to a stretching to the posterior longitudinal spinal ligament which is very pain sensitive. This physiopathological mechanism is the source of the acute back pain in pilots of helicopters.

In this line is very interesting the objective data obtained by Anderson and coworkers (20). They made quantitative measurements of intradiscal pressure in the lumbar spine and the myoelectric activity of back muscles of various postures.

They found lumbar intradiscal pressure was highest with spine flexed anteriorly and myoelectric activity increased with forward flexion of the spine and asymmetric loading for a constant degree of spinal flexion. They concluded increased myoelectric activity was indicative of localized muscle fatigue.

Some authors (11,14) refer than those pilots who complain of transient pain do not have spine muscleskeletal disorders, pain should be the answer to poor posture and is related to muscle spasm or other transient mechanical factor, since it disappears during the flight or immediately after the flight.

On the other hand, the fact of more flight time in the second group made the conclusion that repeated exposures to such flight conditions lead to pathological changes, which would explain that particular simptomatology. Although the same authors mentioned the fact that the symptoms could be related to previous or underlying pathology of the spine which make those pilots more prone to such helicopter stimuli (11,14).

Summing up, although the poor posture alone can cause pain, it is important to consider that this postural condition may be aggravated over the long term by the concomitant exposure to vibration. The combination of these factors over time may act synergistically to cause pathological changes in the spinal system.

And in addition to that we have to consider other pain contributing factors such as:

a. Presence of underlying disease of the spine (congenital disease or trauma).

b. Total flying time of the pilot in rotary wing aircraft

c. Frequency of flights. Symptoms appear more in advance in pilots who fly more than 4 hours/day and more than 40 hours /week or more than 2 hours in a row (16).

d. Muscle tension in order to keep the appropriate handling and control of instruments, depending of the flight type (7).

e. Cool air during open door maneuvers, might affect the lumbar area (10).

f. Age. Hoiber et al (21) found a lineal relation between back pain and age, in addition to the flying time factor

g. Finally, some other variables related to the life style (physical training, sedentarism..) (14).

Objective data obtained by surface electromyography has been used by Anderson et al. (20) and results showed very accurate data in relation to muscular activity. In the same line we think that skin electromyography can provide very reliable information related to muscle response to the stress above mentioned caused by helicopter operations.

OBJETIVES

Purpose of this study will be:

- To compare the right and left side lumbar muscular activity in helicopter pilots under real flight conditions in order to objectively prove the effects of asymmetrical posture on the musculoskeletal system by using surface electromyography.
- To correlate lumbar muscular activity with environmental and other variables such as type of flight, type of helicopter, flight time, age, physical fitness and height.

MATERIAL AND METHODS.

We have included in the study 35 pilots of helicopter of the Spanish Armed Forced. They were destinated or have passed a formation period in the Helicopter Base of the Fuerzas Aeromóviles del Ejercito de Tierra (F.A.M.E.T.) in Colmenar Viejo, Madrid, which consented to carry out a helicopter pilot's course.

It is considered exclusion approach those subjects that were discovered after a brief clinical history that they had some pathology, traumatism or degenerative illness of the spine.

To all the subjects included in the study were carried out a survey to determine the following variables: age, weight, height, body mass index, total hours of flight and hours of flight in specific helicopter. The physical activity data was picked out as a dicotomic variable: - No sport at all.

- One sport is practised at least once a week.

The flights were carried out in two types of helicopters (the HR-12 and the HU-10) and the helicopter cockpit mock-up Frasca model 300H. The HR-12 or Kyowa, it is an American helicopter of 1.360 kilograms, with a capacity of two pilots' transport and three passengers, speed of cruise of 156 Km./h and autonomy of 2 hours 30 minutes. The HU-10 or Huey also American of 4.318 kilograms, with a capacity of transport of three crews and ten passengers, speed of cruise of 166 Km./h and autonomy of 2 hours 10 minutes.

In the HR-12 two types of flights have been picked out. The "basic" or "accommodation", corresponds to the first phase of helicopter pilot's course, the flight is visual and the landings, taking-offs and normal traffic are carried out. And the "tactical manoeuvres" is the second phase of pilot's course and they are visual flights where besides the above-mentioned tactical manoeuvres and formations are also carried out.

In the HU-10 they are also two types of flights selected. The "instrumental" is the advanced phase of the pilot's course, the flight is only carried out with the instruments, and therefore one does not have an external vision. And the "specialisation" or instructors' formation where besides normal and emergency manoeuvres are also made. The flights carried out in the helicopter cockpit mock-up were flights of "instrumental" type.

According to the helicopter and the flight type we include the subjects studied in the following groups:

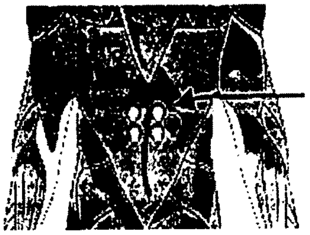
- Basic course in HR-12.
- Tactical manoeuvres course in HR-12.
- Instrumental course in HU-10.
- Improvement course in HU-10.
- Flying in the helicopter cockpit mock-up.

Sometimes the helicopter is piloted on the right or left position in the cockpit with the control instruments of in the left or right front respectively, although the cyclic pitch control and the collective pitch lever, manual controls, are in the same position in both seats. These data are picked out in the survey.

The Muscle Tester ME300 (Mega Electronics Ltd, Kuopio, Finland) is used to measure the muscular activity in the lumbar area. The ME300 is a surface electromiograph that registers simultaneously by means of two channels the potentials of action of two muscles being the sensibility of + / - 1 microvolt.

The knowledge of the potentials of muscular action is since of great interest and the techniques of surface electromyography provides objective data of the electric activity in the muscular cells (22). The muscular activity is measured by monitoring electrods with support of Micropore and solid gel applied directly on the skin, in both paravertebral areas on the lumbar musculature at level of L1-L2. Three electrodes are placed in each side, two actives and one ground separated to about 3 cm and forming a triangle and like one observes in the Figure 2.

Figure 2. Place of electrodes.



To avoid errors in the registration, the test was performed alternating the channels 1 and 2 respectively in the right and left paravertebral muscles. In this way we carry out a comparative isometric test of the right and left lumbar muscles.

The registrations are carried out each one-second during the whole time of registration.

The information received by the surface electrodes is picked out in a microprocessor of small size and reduced weight that the pilot put in one of the pockets of his flight' suit. The registration starts immediately after placing the electrodes in the lumbar region of the pilots. An external marker cable connected to the microprocessor is used to allow us to make different marks it and on/off selects concrete periods of flying in the overall registration.

Measurements:

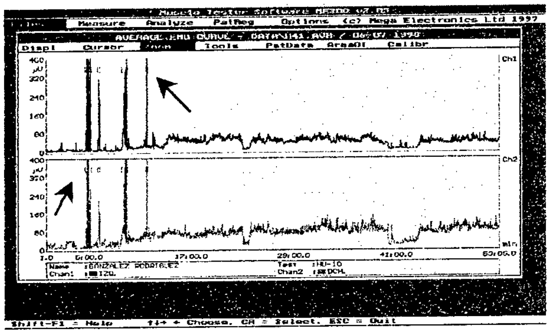
- Baseline. The first period is selected before entering in the helicopter. The pilot remains seated down, in a relaxed position and leaning the back totally in the back of the seat. This first phase it is denominated "basal period". At this time it is explained to the pilot that he should press the device of the marks during the flight when one will take or leave the controls; this is the only way to select the periods of flight just when the pilot has remained in the posture that we want to study. This phase accomplished only in order to test the correct operation of the eletromiograph in a relaxed position.
- Flight. According to how the flight was done, we can obtain one or several phases and once selected

we can study them as one. We called this phase "flight period ".

The data accumulated in the memory of the microprocessor are transferred to a Computer system where they are analysed by a specific program of the ME300 allowing the analysis of the data. The data of both channels are the following: time, minimum and maximum potential, mean and area or the sum of all the potentials of action. The work carried out by the right and the left musculature is expressed in percentages, defining the variable "right prevalence" as the area under the curve of the voltage obtained in the right lumbar area divided by the sum of the right and left areas.

We used new marks on the record handling the ME300 software to annul the interferences produced by the VHF band waves of radio frequency of communication used by the pilots (30 -200Mhz.) as can be seen in Figure 3.

Figure 3. Normal record, with interferences and marks to annul them.



Name : GONZALEZ RODRIGUEZ
Test : HU-10
Chan1 : IZQ.
Chan2 : DCH.

The resulting variables of the survey and the Muscle Tester ME300 are introduced in a database using the Statistical Package for the Social Sciences (SPSS) statistical computer program for Windows Release 6.0. .For the analysis it have been used the tests of comparison of means (t of Student and ANOVA). Chance probability of "p" inferior or equal to 0,05 is accepted as critical for statistical significance.

RESULTS.

The study has been carried out with 35 helicopter pilots that have accepted to participate voluntary in this study. All the pilots are male. The mean age is 28.2 years with a range 23-39 years. The antroprometric characteristic and the age of the participant appears in the Table 1. The 80% of the pilots practise a sport at least once a week.

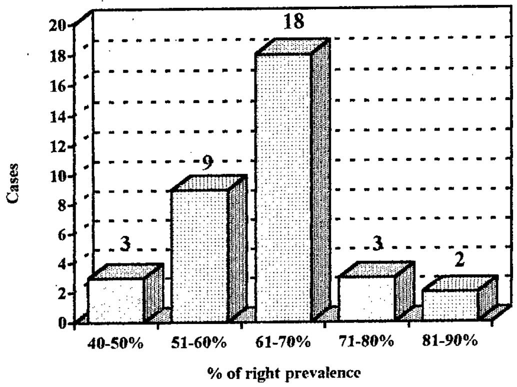
Regarding their experiences as pilots we find a stocking of 577.8 total hours of flight in helicopters (range 56-3300 hours) and a stocking of 342.9 hours of flight in a specific type of helicopter that each of the pilots have carried out the study (range 5-1900 hours).

Of the 35 flights in those that measurements 17 were obtained with the helicopter HR-12, 12 with HU-10 and 6 with the Trainer. As for the type of flight 16 have been "Instrumental", 9 "Tactical Manoeuvre ", 8 "Accommodation" and 4 of "Improvement." In Table 2 it shows the distribution of the types of flight according to the kind of helicopter. The pilot's position in the cockpit has been in the right side in 28 cases (80%) and in the left side in 7 cases (20%).

The maximum duration of the flight was of 80 minutes being the minimum of 16 minutes, in 75% of the cases the duration oscillated between 30 and 60 minutes. (mean+/- DS; 43.8 15.9). Four (11%) of the thirty-five pilots they referred light lumbar nuisances after the test.

Only 3 subjects (9%) presented a larger activity in the left lumbar muscular side than in the right one, being for the 32 remaining (91%) predominate the activity of the region lumbar right. The mean percentage of "right prevalence" for the total of the cases is 63.1%. In Figure 4 the distribution of the right prevalence is picked up for the 35 pilots.

Figure 4. Distribution of right prevalence in studied pilots.



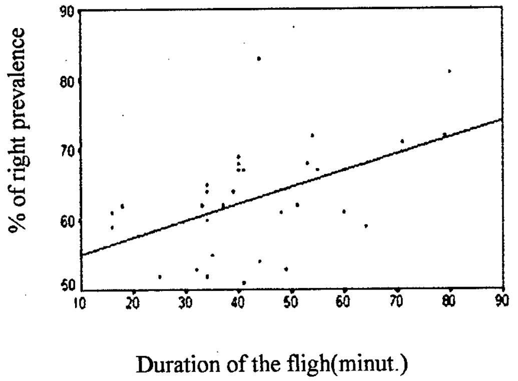
To study the association of the variable "right prevalence" with the rest of the variables collections, only included in the analysis 32 pilots with values of "right prevalence" superior to 50%. In Table 3 the distribution of the value means of the characteristic studied antropometric is shown for three levels of "right prevalence." As it is reflected in this table neither the weight, height neither the corporal mass index associated statistically in a significant way to our variable in the study.

When increasing the level of "right prevalence" so much the mean values of the age and total hours of flight as in specific helicopter in with the test was carried out also increase, although this tendency is not statistically significant (Table 4).

It is statistically significant the association among the level of "right prevalence" and the duration of the flight, being increase in the mean duration from the flight when increasing the level of "right prevalence." These results are picked up in Table 5.

In Figure 5 the regression straight line is shown for the relationship among the variables "right prevalence" and "duration of the flight"

Figure 5 Distribution of right prevalence in function of the durationof the flight.



When comparing the value means of "right prevalence" according to the different types of used helicopters we do not find significant differences, neither not existing according to the type of carried out flight (Table 6) nor according to the groups defined in the material and methods section as a result of the crossing of helicopter type and flight. Neither the subjects that do not practice sport nor those that suffered nuisances after the realisation of the study have demonstrated to have figures stockings of "right prevalence" statistically different from those that do not present these characteristics.

DISCUSSION.

In order to study back pain in pilots, most of the works have obtained their results by questionnaires or others methods which get data purely subjective.

There are very few papers which have made an objective study. Among them we would like to emphasize in which was used surface electromyography to obtain an objective and fiable result by means of a fast and bloodless test of the muscle activity of the muscular activity (22).

For example, Le Menn et al. (8) studied the myoelectric signals from the trapezius and the sternocleidomastoid muscles on fighter aircraft aircrew, to analyze the fatigue of these neck muscles during head movements under high-Gz loading in flight.

Another reference work which used a surface electromyography was performed by Anderson et al. (20). They made quantitative measurements of the myoelectric activity of the back in various postures. They concluded increased myoelectric activity was indicative of localized muscle fatigue, because the activity increased with asymmetric loading for a constant degree of spinal flexion.

Hamalainen and co-workers (23) used the Muscle Tester ME3000 to investigate the strain in fighter pilots caused by Gz forces and head movements on the cervical erector spinae muscles during flight missions. This surface electromyographic records action potentials, they calculated the relative strain on the cervical muscles by comparing these potentials with those representing the highest maximal voluntary contraction produced by the same muscles in each subject. The mean data obtained during flight missions were expressed in percent of the maximal voluntary contraction (100%).

This method has its limitations, it records only muscular activity and does not show directly the stress on intervertebral discs or ligaments, nevertheless these authors assumed to exist some correlation between muscular activity and compression of the structures of the cervical spine.

The ME300 is a EMG surface similar to which Hamalaine used (23) in his work that measures the action potentials by means of two channels that allow us to carry out a comparative isometric test of the right and left lumbar musculature.

The work carried out by the right and left lumbar musculature is expressed in percentages regarding the total activity (100%), denominating to the percentages right and left, respectively, right prevalence and left prevalence. According to that we can study the difference among the work carried out by the right and the left lumbar musculature and in this way we can demonstrate the pilot's asymmetric posture.

In the period of flight, that is to say, in the sum of the phases during which the pilot meets with the hands using the manual controls, the work carried out by the right lumbar musculature was bigger in 32 pilots out of the 35 studied (91%) and the work of the left musculature was lightly greater in the remaining three (9%).

In Figure 4 the distribution of the right prevalence in the pilots studied is represented: 3 pilots (9%) had a right prevalence below 50%, concretely between the 40 and 50%; the largest group, 18 pilots (51%) represented those whose right prevalence oscillated between 61 and 70%; 9 pilots (26%) were between 51 and 60%; 3 (9%) between 71 and 80% and only two pilots (6%) they had a right prevalence between 81 and 90%.

For being superior the number of cases of great activity of the right musculature with respect to the left one, were only used in the study the 32 pilots whose right prevalence, in the period of flight, was greater than 50%.

These data take us clearly to the conclusion that, in more or smaller measure, the pilot during the flight, when he is using the manual controls, he does not maintain a symmetrical posture and that makes him contract a side more than the other.

They are many authors that have referred to this asymmetry in the posture of the flight in their publications (3,4,6,7,10,11,13,14,15,16). They all coincide in that the helicopter pilot of while flying maintain their trunks slightly forward and rotated to the left, this would explain the biggest right contraction.

This great right contraction shows more the longer the flight. In Table 5 the mean duration of flights are exposed in different levels of right prevalence, this way the pilots whose right prevalence oscillated between 50 and 60%, carried out flights of mean 37.4 minutes; between 61 and 70% the flights lasted 40.58 mean minutes; and lastly in the pilots whose mean flight was 65.6 minutes the right prevalence was great than 70%.

This increase of the right prevalence in connection with the flight duration was statistically significant ($p < 0.001$), is described in the regression straight line that it appears in the Figure 5.

There are authors that have related the flight duration the with the appearance of the back pain (16,18,24), even Shanahan et al. (11) carried out a study in which they considered that the lumbar pain in the helicopter pilot appeared, on the average, in 88 minutes of flight.

We think that this narrow relationship between the greatest right contraction and the flight duration, is due to a maintaining for a long period of time an asymmetric posture its consequence is a great muscular tension and for that reason there a great difference between the right and the left muscular activity.

As for the relationship between the pilot's hours of flight, in any helicopter or in a specific helicopter and the great right prevalence, we see in the Table 4 that, although a relationship has not been demonstrated statistically significant, if a tendency exists to a great right muscular activity in the pilots with more flight hours, mainly regarding the specific hours in the studied helicopter.

Shanahan et al. (11) carried out a work studying two groups of pilots, those that had pain in the flight and those that had not, demonstrating that the first group of pilots had significantly ($p < 0,0001$) more flight hours. There are authors like Sliosberg (25) considers that the chronic back pain appears on the average in pilots with 300 flight hours or Colleau (26) starting from more than 500.

Shanahan et al. (11,14) suggested that, the fact that the pilots with more flight experience had a back pain with some specific characteristics (bigger duration, irradiation to inferior members, etc.) it makes one think of some evolutionary muscleskeletal pathology like consequence from a chronic exhibition to some adverse conditions.

Our opinion about the fact that there is more right prevalence on the left side in aircrew with a larger amount of flight time, seems to be related with the pathological problems that Shanahan et al. noticed in the most experience pilots. The increased pain presented it should mean an increased amount of contraction.

In the Table 4 we can also see the tendency to a greater activity of the right lumbar musculature regarding the left in connection with the age, mainly he/she shows in the youngest pilots in which the right prevalence is smaller. We think that age and experience in flight are intimately united.

The rest of variables like: height, body mass index, type of flight and helicopter, physical activity and right and left position in the cockpit did not have statistical significance regarding the right prevalence.

Possibly they could have appeared other significant associations with some of these variables. Due to the fact of the small numbers of cases, we think that 32 cases are few, if we group them to obtain some association statistically significant.

In this sense, we think it could be advisable to widen the study with more cases since it seems that the electromiograph used has completed the objectives to show objectively the pilot's asymmetric position in the helicopter during flight.

Although the ME300 mostly measures muscular activity, this study allows us to compare the muscle load performed by both sides in aircrew members. These data never have been reported. This work open a very promising line of research, that will add in the future very valuable data to be used in the development and ergonomic design of the helicopter cockpits.

Table 1. Antropometric characteristics and age of the pilots.

	Mean	Standard deviation	Range
Age (years)	28	3.9	23-39
Weight (kg)	78,57.	11	60-110
Height (m)	1,77	0.07	1.67-1.93
Corporal mass index (Kg/m^2)	24.9	2.7	20,1-31,8

Table 2. Kind of flight and helicopters.

	Kind of flight			
Helicopter	Tactical Manoeuvres	Accommodation	Improvement	Instrumental
HR-12	9	8	-	-
HU-1H	-	-	4	8
Cockpit mock-up	-	-	-	6

Table 3. Appearance of the antropometric characteristic for different levels of right prevalence.

	Measures		
Level of "right prevalence"	I.M.C. (Kg/m^2)	WEIGHT (Kg)	HEIGH (m)
50-60%	24,89	76,60	1,75
61-70%	24,36	77,58	1,78
>70%	25,05	77,80	1,76
Statistic signification (p)	*0.8*	*0.9*	*0.4*

Table 4. Appearance of the age and the experience as pilots for different levels of right prevalence.

	Means		
Level of "right prevalence"	AGE (years)	SPECIFIC STOKING HOURS	STOKING HOURS
50-60%	26.40	187	384
61-70%	29.00	371	657
>70%	28.40	525	693
Statistic signification (p)	*0.5*	*0.4*	*0.5*

Table 5. Appearance of the duration of the flight for different levels of right prevalence.

Level of "right prevalence"	***DURACIÓN (minutes)***
50-60%	37.40
61-70%	40.58
>70%	65.60
Statistic signification (p)	0.001

Table 6. Comparison of the percentages means of right prevalence according to type of helicopter and kind of flight.

	CATHEGORIAS	"right prevalence" mean percentages	***Statistic signification***
Kind of helicopter	HR-12	60.7	*0.7*
	HU-1O	64.5	
	COKPIT MOCK-UP	66.7	
Kind of flight	INSTRUMENTAL	66.3	*0.2*
	TACTICAL MANEUVERS	59.9	
	ACOMODATION	61.4	
	IMPROVEMENT	60.3	

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LES RACHIALGIES DU PILOTE D'HELICOPTERE DE L'ALAT :Résultats d'une enquête à propos de 560 réponses

ALAT HELICOPTER PILOT RACHIALGIES : Results of an enquiry concerning 560 answers

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RESUME

L'analyse de ces résultats comparés aux précédents (1976) permet d'enregistrer une prévalence des rachialgies du pilote d'hélicoptère de l'ALAT qui progressent de 49,15% à 66% (+17%). Cette augmentation concerne à la fois, les cervicalgies isolées (+7,20%) et les localisations aux deux étages : lombaire et cervical (+14,5%).
Mais les lombalgies isolées ont diminué (-16,5%).

La progression des cervicalgies peut être expliquée par l'importance prise par le vol de nuit dont 40% des heures de vol sont effectuées avec des jumelles de vision nocturne, dont le poids (980 g) s'ajoute à celui du casque (1500 g).

Par ailleurs, l'amélioration technologique du parc hélicoptères, grâce à la réduction du phénomène vibratoire (généralisation des pales plastiques entre autres) a permis la réduction des lombalgies.

Mots clés : Rachialgie - Personnel navigant - Aptitude - Vol de nuit JVN.

SUMMARY

The analysis about these results compared with the previous ones (1976) allows to point out that rachialgies of helicopter pilots are prevailing and are increasing from 49,15% to 66% (+17%). This increase implies both isolated cervicalgies (+7,20%) and locations at two levels: the back and the neck.
But isolated lombalgies are decreasing (-16,5%).

The increase of cervicalgies could be explained by the importance of the night flight; 40% of flight hours are out when equipped with night vision goggles, the weight of which (980 g) is added to the helmet's one.

In other respects, the technological improvement of the helicopters fleet, thanks to the reducing of vibrations (generalization of plastic blades among others) has given reducing of lombalgies.

Key words : Rachialgy - Crew members - Aptitude - Night vision goggles flight

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I/ INTRODUCTION

La dernière enquête statistique concernant les rachialgies du pilote d'hélicoptère de l'ALAT (RPH) a été réalisée en 1976 et 1978 par MARCILLAT (1).
Il nous a semblé utile de refaire le point sur cette question 20 ans plus tard, sachant l'important développement acquis par l'ALAT.

En effet, il faut citer :

- le renouvellement et le renforcement du parc hélicoptère (557 à 691 soit + 24%),
- l'acquisition de nouveaux matériels (tirs HOT, canon 20 mm, jumelles de vision nocturne, etc...) ou concepts (combat aéromobile pour un futur combat de nuit avec le viseur Viviane),
- l'engagement sur les récents théâtres d'opération (guerre du Golfe) ou autres missions humanitaires (Somalie, Cambodge, ex Yougoslavie).

Une récente enquête par l'envoi d'un questionnaire type sur les RPH (Rachialgies du pilote d'hélicoptère) dans toutes les unités ALAT, (Ecole, régiments d'hélicoptères de combat, groupes d'hélicoptères légers, etc ...) a permis le recueil de 560 réponses soit environ 30% du personnel navigant de l'ALAT (pilotes et mécaniciens navigants).

Cette étude n'abordera pas en détail l'étiopathogénie des RPH, à savoir :

- les facteurs mécaniques avec les vibrations mécaniques et aéronautiques.
- les facteurs posturaux (positions de pilotage et siège).

A/ RAPPEL HISTORIQUE.

1. R.P.H ET DONNEES DE LA LITTERATURE.

Tableau n° 1

AUTEURS	ANNEE	POPULATION P.N	R.P.H	OBSERVATIONS
Sliosberg (3)	1962	128	87.5%	Pilotes essais et A.F.N
Colleau (4)	1974	29	86%	Aéronavale
Marcillat (1)	1976	118	49.15%	ALAT
Auffret Delahaye (2)	1977	12	66%	Pilote CEV
Marcillat (1)	1978	85	38.8%	ALAT

Ces chiffres montrent bien l'importance des RPH étudiées par de nombreux auteurs. A noter que le nombre de cas des pilotes observés, est relativement restreint (de 12 à 128) par rapport à la "statistique 1996" présentée dans cet article (560).

2. EVOLUTION DU PARC HELICOPTERES 1976 - 1996

Tableau n° 2

	TOTAL	HELICOPTERES 1° GENERATION BELL - AL II - AL III	HELICOPTERES 2° GENERATION GAZELLE - PUMA	HELICOPTERES 3° GENERATION COUGAR - FENNEC
1976	457	354	103	0
	100%	77,5%	22,5%	0
1996	684	175	475	34
	100%	26%	69,5%	4,5%

En 20 ans, le parc hélicoptères ALAT a augmenté de 18,5% et il peut être constaté le remplacement des hélicoptères de 1ère génération (à fort niveau vibratoire) par des appareils dits de 2ème et 3ème génération (sièges plus confortables et arrivée des pâles en plastiques réduisant le niveau vibratoire).

Par ailleurs, il faut noter au cours de cette période la diminution des heures de vol de l'ordre de 4,5%.

B/ PRESENTATION DE LA POPULATION ALAT ETUDIEE.

Tableau n° 3

	PILOTES	MECANICIENS NAVIGANTS	TOTAL
NOMBRE	476	84	560
POURCENTAGE	85%	15%	100%

- Les pilotes ayant répondu à notre questionnaire (anonyme) sont répartis sur deux types d'aéronefs :

  - "Hélicoptères légers" : Alouette II, Alouette III, Gazelle et Fennec (Ecureuil),

  - "Hélicoptères lourds" : Puma et Cougar (Super Puma).

- Les mécaniciens navigants moins nombreux (15% de notre étude) ont une fonction uniquement à bord des Pumas ou Cougars.

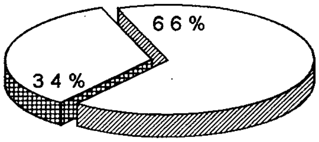
II/ RESULTATS ET ANALYSE.

1. REPARTITION DE LA POPULATION P.N ALAT RACHIALGIQUE (RPH) ET NON RACHIALGIQUE.

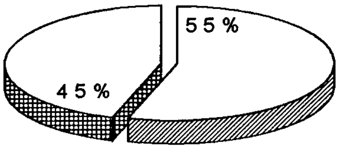
Tableau n°4

	PILOTES		MECANICIENS NAVIGANTS		TOTAL	
	Nombre	%	Nombre	%	Nombre	%
Avec RACHIALGIES (RPH)	311	66%	46	55%	357	64%
INDEMNES	165	34%	38	45%	203	36%
TOTAL	476	100%	84	100%	560	100%

PILOTES



MECANICIENS NAVIGANTS



L'analyse de ces chiffres, permet de formuler les remarques suivantes :

- 66% des pilotes présentent des rachialgies, soit une prévalence de + 17% par rapport à la précédente enquête (1976) où il avait été noté 49,15% de RPH.

- pour la première fois, la population des mécaniciens navigants non interrogée à ce jour, présente elle aussi une symptomatologie RPH : 55%.

2/ REPARTITION DES RACHIALGIES (RPH) SELON LE NOMBRE D'HEURES DE VOL ACCOMPLIES.

Tableau n° 5

Moyenne HEURES de VOL (PILOTE)	R.P.H.	Moyenne HEURES de VOL (MEC.NAV)
2 800 h.	Lombalgie isolée	1 900 h.
3 070 h.	Cervicalgie + Lombalgie	**1 800 h.**
2 800 h.	Cervicalgie isolée	1 900 h.

* 2800 heures de vol représentent la valeur moyenne pour laquelle, est enregistrée une symptomatologie RPH à l'étage lombaire ou cervical.

* A noter que les mécaniciens navigants présentent en moyenne des 1 800 h soit 1000 h avant les pilotes, des rachialgies à la fois, aux deux étages les plus sensibles : lombaire et cervical.

Ceci peut être expliqué par la qualité moindre du siège (pliable et à dossier rabattable) et à des actions en vol imposant des flexions antérieures et postérieures itératives, pour avoir accès aux commandes.

3/ REPARTITION DES RACHIALGIES (RPH) SELON L'ETAGE RACHIDIEN.

La localisation préférentielle à l'étage lombaire (46 %) pour les pilotes est conforme aux données établies. En effet Delahaye et coll (2) avaient décrit pour cette population "le segment rachidien critique" en insistant sur le rachis lombaire et la charnière lombo-sacrée.

Ce tableau montre aussi un pourcentage significatif concernant une atteinte isolée du rachis cervical pour 9 % des pilotes rachialgiques.

Une localisation RPH aux deux étages : cervical et lombaire est notée pour 21,5 % des pilotes et 35 % des mécaniciens navigants.

Ces valeurs doivent être comparées avec celles d'il y a 20 ans.

Tableau n° 6

R.P.H.	PILOTES RACHIALGIQUES (311 / 476)		MEC. NAVIGANTS RACHIALGIQUES (46 / 84)	
	NOMBRE	**%**	**NOMBRE**	**%**
LOMBALGIE ISOLEE	**144**	**46%**	**10**	**22%**
CERVICALGIE ISOLEE	**67**	**21.50%**	**16**	**35%**
CERVICALGIE ISOLEE	**27**	**9%**	**9**	**20%**
DORSALGIE + LOMBALGIE	**24**	**8%**	**1**	**2%**
CERVICALGIE + DORSALGIE + LOMBALGIE	**17**	**5.50%**	**4**	**8.50%**
DORSALGIE ISOLEE	**24**	**8%**	**1**	**2%**
CERVICALGIE + DORSALGIE	**11**	**3.50%**	**4**	**8.50%**
NON REPONDU	**5**	**1.50%**	**2**	**4%**
TOTAL	**311**	**100%**	**46**	**100%**

4/ STATISTIQUE ALAT : RACHIALGIE (RPH) ET ETAGE RACHIDIEN.

Tableau n° 7

1976	R.P.H.	1996	DIFFERENCE
62.5 %	Lombalgie isolée	46 %	⇓16.5 %
1.8 %	Cervicalgie isolée	9 %	⇑ 7.20 %
7 %	Cervicalgie + Lombalgie	21.5 %	⇑ 14.5 %
28.7 %	Divers	23.5 %	

Cette comparaison permet de formuler les remarques suivantes :

- diminution de 16.5 % du pourcentage des lombalgies isolées.
- mais augmentation de celui des cervicalgies isolées (+ 7.20 %) et des formes mixtes incluant les segments : cervical et lombaire (+ 14.5 %)

L'amélioration technologique du parc hélicoptères avec la réduction du phénomène vibratoire (mise en place de pâles en plastique) et un meilleur confort des sièges peut expliquer la diminution des lombalgies.

Par ailleurs la part de plus en plus importante représentée par le vol de nuit (+ 4% en 20 ans : de 7 à 11%) et plus particulièrement avec des jumelles de vision nocturne ou JVN, est probablement la cause de l'augmentation des cervicalgies.

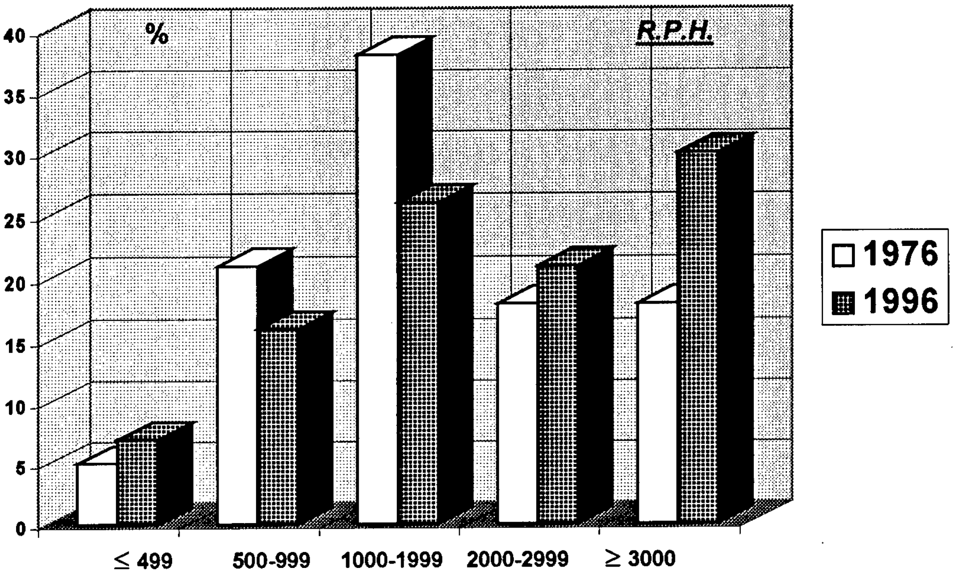
Le type de vol (40 % du vol de nuit) impose le port de jumelles dites à intensification de lumière, dont l'équipement (980 grammes) s'ajoute au poids du casque (1500 g). De plus, la limitation du champ visuel à 40° implique pour la vision périphérique un balayage permanent selon un plan horizontal par le rachis cervical.

La nécessaire prise d'information visuelle au niveau de tableau de bord (vitesse, cap, hauteur sol grâce à la sonde...) impose des mouvements répétés, de flexion extension du rachis cervical. Ceci s'oppose, au balayage en vision périphérique précédemment décrit.
De plus, les instruments sont observés selon une technique particulière "sous la jumelle" avec recours à une très brève vision nocturne classique, puis retour immédiat aux JVN.

Ceci explique l'importante charge de travail à la fois physique et psychosensorielle du vol de nuit sous jumelle de vision nocturne.

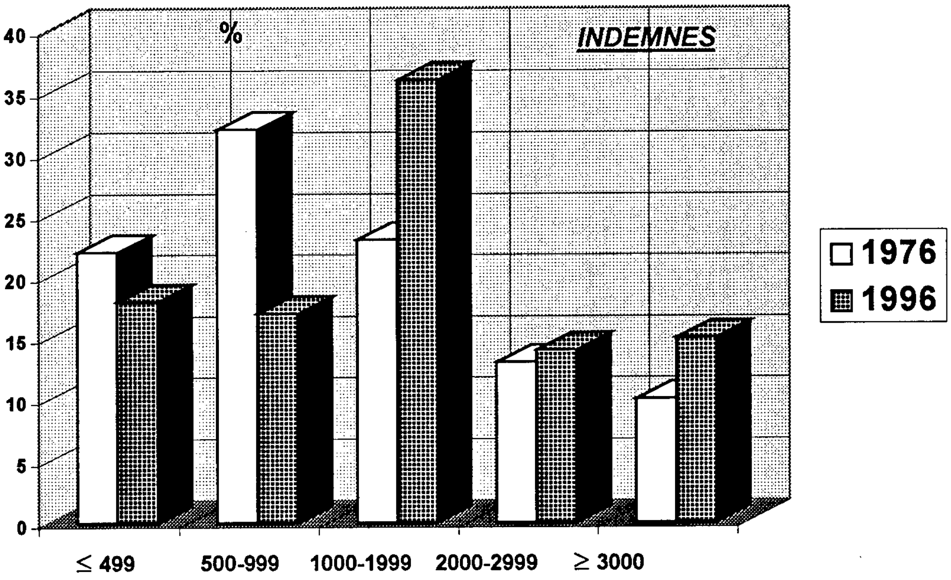
5/ COMPARAISON EVOLUTIVE (1976 - 1996) DES POPULATIONS RACHIALGIQUES (RPH) ET A SYMPTOMATIQUES EN FONCTION DU NOMBRE DES HEURES DE VOL.

Tableau n°8



On constate un déplacement du seuil moyen de cette population PN rachialgique de la tranche 1000/2000 heures de vol (estimée à 38 %) vers celle de 3000 heures de vol et plus (estimée à 30%)

Tableau n°9



Ici, il est noté un déplacement du seuil moyen de la population PN non rachialgique de la tranche 500/999 heures de vol (estimée à 32 %) vers celle de 1000/1999 heures de vol (estimée à 36 %).

Au total, ce déplacement favorable des seuils pour les deux populations étudiées, est à mettre sur le compte des progrès technologiques en matière de construction des hélicoptères.

6/ PRATIQUE DU SPORT ET CORRELATIONS ENTRE POPULATIONS: RPH ET NON RACHIALGIQUE.

Tableau n° 10

PERSONNEL NAVIGANT	PN SPORTIFS		PN NON SPORTIFS		TOTAUX	
	Nombre	%	Nombre	%	Nombre	%
Population RPH	206	78 %	151	52 %	357	100 %
Population Indemne	59	22 %	144	48 %	203	100 %
TOTAL	265	48 %	295	52 %	560	100%

Les chiffres permettent d'observer que les sports pratiqués par la population PN, ne sont pas toujours susceptibles de provoquer un effet bénéfique en matière de prévention des rachialgies.

Dans la population RPH, il est noté 58 % de pilotes sportifs et 42 % de pilotes non sportifs.

Il est difficile de tirer des conclusions définitives, mais les remarques suivantes peuvent être formulées :

- la pratique prédominante du footing (facilité d'exécution) ne semble pas être le sport le plus indiqué chez des pilotes d'hélicoptères dont on connaît le point faible représenté par le rachis et le phénomène vibratoire.

Il doit être conseillé en matière de footing le port obligatoire de chaussures adaptées et le respect de la contre-indication du footing en cas de rachialgie avérée.

- par ailleurs cette enquête à permis de constater que certains sports étaient insuffisamment pratiqués comme la natation (difficultés...de mise en place de piscines) ou la gymnastique adaptée.

Un protocole "anti-RPH" avait été constitué en école de formation initiale à Dax (Marcillat) avec pour objectif le renforcement musculaire de la paroi abdominale et dorso-lombaire (exercices pratiques sous le contrôle de moniteur EPS et Kinésithérapeutes).
Il conviendrait d'insister à nouveau sur l'intérêt de développer ce principe aussi bien en école qu'en unités, après sensibilisation du personnel navigant ALAT devant le problème représenté par les rachialgies et le vol en hélicoptère.

Cette démarche passe aussi, par l'obligation d'une mise en place, de salles de musculation au sein des différentes unités ALAT.

III/ THERAPEUTIQUE ET APTITUDE PN.

1/ CONDUITE THERAPEUTIQUE ET POPULATION PN RACHIALGIQUE

Tableau n°11

▨	**PILOTES (311)**		**MECANICIENS NAVIGANTS (46)**	
TRAITEMENT	**Nombre**	**%**	**Nombre**	**%**
MEDICAL	**22**	**7%**	**3**	**7%**
CHIRURGICAL	**11**	**3.50%**	**8**	**17.50%**
TOTAL	**33**	**10.50%**	**11**	**24.50%**

44 cas (pilotes et mécaniciens navigants) ont fait l'objet d'un traitement, et pour 19 d'entre eux une intervention chirurgicale a dû être réalisée.

A noter que la population mécanicien navigant pour laquelle a été noté une localisation lombalgique plus précoce (≅ 1000 Heures de vol) par rapport aux pilotes, présente un taux d'intervention chirurgicale supérieur de 5 fois environ à celui de la population pilote (inconfort du siège déjà décrit : Tableau n°6)

2/ APTITUDE PN : RESULTATS APRES EXAMEN DES DOSSIERS PAR LA CMSPNA.

Pendant la période allant de 1985 à 1995, la Commission Médicale Supérieure du Personnel Navigants des Armées (CMSPNA), a été saisie par l'étude de 24 dossiers ALAT, ayant pour objet une étiologie rachidienne.

2.1 . Répartition selon l'étage rachidien lésionnel

Tableau n° 12

Nombre de dossiers	**Etage cervical**	**Etage lombosacré**	**Etage cervical et lombosacré**
24	7	16	1
%	29 %	67 %	4 %

Ces valeurs sont à rapprocher de celles de notre enquête présentées dans le tableau n° 13, où il était noté 70% de cas opérés au niveau de l'étage lombosacré.

Parmi ces dossiers, pour 7 d'entre eux (29%), l'expertise psychologique a retenu une désadaptation au vol, par baisse de la motivation et réaction névrotique associées.

2.2 Résultats

Après étude de ces 24 dossiers présentés par le commandement de l'ALAT, la CMSPNA a adopté les dispositions suivantes :

* avis favorable pour l'attribution de 10 dérogation aux normes médicales d'aptitude à la fonction PN.

* avis défavorable à la poursuite de toute activité aéronautique pour les 14 autres cas.

Tableau n° 13

DEROGATIONS	INAPTES PN DEFINITIFS
10	14
42 %	58 %

IV./ CONCLUSIONS

Cette étude statistique a permis de faire le point sur les rachialgies du pilote d'hélicoptère ALAT.

Cette pathologie très spécifique, est liée à différents facteurs :

- le phénomène vibratoire (basse fréquence)
- une ergonomie complexe (poste de pilotage, position asymétrique de l'équipage, siège inconfortable, port du casque et des JVN...)

La comparaison avec les précédentes constatations, sur une période couvrant ces vingt dernières années montre une progression régulière des rachialgies.

La part croissante représentée par le vol de nuit avec JVN, explique l'importance nouvelle prise par les cervicalgies qui s'ajoutent aux "classiques" lombalgies du pilote d'hélicoptère.

Toutefois certaines mesures ont permis de limiter cette prévalence RPH avec recul des seuils grâce à :

- une meilleure technologie aéronautique et l'arrivée de nouveaux hélicoptères (Ecureuil ou Fennec et Super-Puma ou Cougar)
- l'application de mesures préventives hygiénodiététiques (gymnastique adaptée).
- une sélection renforcée avec la création d'un standard hélicoptère "norme H" et la définition d'un segment rachidien critique lombosacré.

L'importance prise par les cervicalgies liées au développement du "vol de nuit JVN" peut inciter à ajouter au segment critique précité, le rachis cervical.

Enfin l'arrivée des hélicoptères de 4° génération (TIGRE et NH 90) bénéficiant des derniers acquis technologiques (avec l'intégration d'une meilleure ergonomie) et la diminution des heures de vol permettent d'envisager un avenir plus favorable, pour une diminution des rachialgies.

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NAVAL AND MARINE CORPS ROTARY WING OVER WATER MISHAPS AND THE LIFE RAFT IMPROVEMENT PROGRAM

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SUMMARY

U. S. Navy Instruction (OPNAVINST 3710.7Q) states "Life rafts of sufficient capacity to accommodate passengers and crew shall be provided in all aircraft when there would be a significant risk of water entry in the event of a mishap". The inability to successfully deploy life rafts in over water ditching scenarios has long been recognized by helicopter aircrews in the U.S. Navy and Marine Corps. The rafts' size and weight limits the stowage options and impacts the deployment characteristics of current aviation life rafts. A proposal co-sponsored by the Aircraft Equipment Reliability and Maintainability Improvement Program (AERMIP) and the Affordable Readiness Program has targeted current life raft technology in addressing these deployment issues. . By taking advantage of this technology, the U.S. Navy can provide the aviation community with a state-of-the-art life raft that will dramatically improve the deployment capabilities as well as, reducing current maintenance inspections and logistical support requirements. This paper will address new raft materials, shapes, sizes, inflation systems, along with other design features including life raft capacity as it will apply to current and future aircraft assets. The monetary benefits will also be addressed. In addition, the options for incorporation of improved manual/automatic deployment systems that are internally/externally mounted will be presented.

LIST OF SYMBOLS

MPLR-Multi Place Life Raft
EPA-Environmental Protection Agency
OSHA-Occupational Safety and Health Administration
AERMIP- Aircraft Equipment Reliability and Maintainability Improvement Program
TMS- Type, Model, Series of Aircraft
MIL-STD 810E-Miltary Standard that governs environmental testing.
TSO-Technical Standard Order-Department of Transportation Order that governs life raft design and testing for aviation applications

BACKGROUND

The need for new and improved life rafts for use in Navy and Marine Corps Fixed-wing and Rotary-wing communities is supported by the statistics associated with life raft deployment...specifically those connected with helicopter over water mishaps. In reviewing U.S. Naval Safety Center data that covered a span of 13 years (1985-1997) we discovered that only 30 out of 262 survivors (11 percent) were able to deploy their own life rafts. The inability of the crew to deploy their rafts from an inverted rapidly sinking helicopter is easily understandable. Raft size and weight, which dictate stowage locations, are the major contributing factors that impact the ability to deploy a raft[1]. These issues must be addressed if the U.S. Navy hopes to improve upon the deployment statistics.

INTRODUCTION

A proposal was submitted in August 1997 to the Aircraft Equipment Reliability and Maintainability Improvement Program (AERMIP) to improve the MPLRs. The goal of this joint program is to replace current MPLRs in aircraft with cost effective new technology equipment exhibiting superior construction, improved strength, and better reliability. The benefits the Navy can expect from this program include rafts that:

- are lighter, smaller
- are easier to deploy manually
- can be remote mounted for automatic deployment (future option)
- require less scheduled maintenance
- require little or no Intermediate Level Maintenance support
- incorporate improved manufacturing techniques

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- require less logistical support

CURRENT RAFT CHARACTERISTICS

Current Multi-Person Life Raft (MPLR) designs, materials, manufacturing techniques, and inspection cycles are outdated and expensive. Rafts that are carried aboard today's Navy and Marine Corps Fixed-wing and Rotary-wing aircraft are manufactured with a neoprene coated nylon-based fabric that requires use of Polychloroprene adhesives for construction. This manufacturing process is labor intensive, requires a large amount of manufacturing floor space, and poses health and environmental hazards. Also, neoprene coated nylon-based fabric is becoming more difficult and expensive to procure due to the imposition of expensive EPA and OSHA restrictions concerning the use of solvents. Current MPLRs cannot be reduced volume packed due to outdated construction techniques and associated materials. This in itself limits stowage locations and deployment capabilities due to bulk and weight.

Another problem is the life expectancy rates of multi-person life rafts. Failure rates have been linked with the frequency of inspection cycles. Current MPLRs require an inspection every 224 days. Raft inspection requires unpacking, inflating, deflating, and re-packing the raft. Seams created through adhesive joining of materials constitute weak points in the equipment and fail after a number of inspections. Because adhesive joining deteriorates, a reduction in the strength and reliability of the equipment has been observed. Routine inspections involving a full operational load are performed every 224 days. Functional testing (functional testing uses the actual gas inflation cylinder) is performed on every forth inspection cycle and a significant number of material failures have been recorded.

PROPOSED RAFT CHARACTERISTICS

A new family of rafts constructed from lightweight materials that are heat-sealed and can be reduced volume packed would dramatically improve the handling, stowage and deployment characteristics. These improved construction and packing techniques also, enable extended inspection cycles resulting in immediate saving in scheduled maintenance costs.

Raft Capacity and Size

The Fleet Master Plan must be taken into account when addressing the subject of upgrading the Fleet with new, multi-person life rafts. Raft capacity is a primary factor in targeting cost, logistics, stowage, and accessibility. Raft capacities must be capable of meeting the projected Plan agenda, as the expected mix of Fleet aircraft will change between 1998 and 2012 (see Table I). After reviewing the projected aircraft mix and considering various raft-sizing criteria, it is possible from a cost and efficacy point-of-view that one common raft size could meet the requirements of tomorrow's fleet. Qualification and environmental testing, the reduction in proliferation of inventory items, and unit cost would all benefit through use of a single size MPLR. It is proposed that the optimal size would accommodate eight people, be of less weight (under 50 pounds), and lend itself to half the packable volume of a current seven-man raft configuration. A lighter, smaller MPLR that is easily stowed would, also, be easier to handle in a ditching situation. Additionally, external mounting these rafts on many Navy and Marine aircraft could be accomplished utilizing current technology.

The rated capacity for an eight-person raft size would allow 5.0 square feet per person without overlapping and a back support measuring at least eight inches high as well as meeting the following specifications.

1. Rated Capacity-8 personnel at a deck sitting area of 4.5 sq. ft.
   per person
2. Overload Capacity-not less than 50%
3. Back support of at least 15 inches wide and 8 inches high.

Buoyancy

An average occupant weight of 200 lbs. will be used with the following parameters.

1. Freeboard of at least 12 inches at overload capacity with buoyancy tubes at minimum operating pressure and at least 6 inches of freeboard at rated capacity with critical tube/chamber deflated and the remaining tube/chamber at minimum pressure.
2. Buoyancy must be provided by two independent tubes; or if single tube design, internal bulkheads must divide the flotation tube into at least two separate chambers.

Inflation system

The inflation system shall be constructed to no/minimum leakage standards and

1. Arranged so that failure of one tube/chamber or manifold will not result in loss of gas from the other chambers
2. Inflation equipment does not interfere with boarding operations.
3. Components meet DOT specification 3AA (49 CFR 178.37) or Specification 3HT (49 CFR 178.44).
4. System is capable of inflating the raft to full size while fully submerged.

Canopy

A canopy system is proposed for occupant protection. It may be joined to the body of the MPLR by heat sealing or adhesives. In either case, it shall not compromise the flotation system if damaged, and it would be either completely self-erecting or have self-inflating beams. In addition, the canopy would

Table 1. Raft Requirements by TMS

AIRCRAFT INFORMATION			1996 INVENTORY		1996 REQUIREMENT		2012 INVENTORY	
AIRCRAFT TMS	AIRCRAFT CAPACITY	NUMBER OF RAFTS REQUIRED	#ACFT	# RAFTS REQUIRED	# ACFT	# RAFTS REQUIRED	# ACFT	# RAFTS REQUIRED
SH-60R	6	1	0	0	0	0	185	185
CH-60	17	3	0	0	0	0	39	117
HH-60	12	2	39	78	52	104	0	0
SH-60F	6	1	76	76	62	62	0	0
SH-60B	6	1	168	168	175	175	0	0
SH-2G	6	1	10	10	10	10	0	0
H-46	28	4	320	1280	320	1280	245	980
H-3	15	2	56	112	68	136	0	0
UH-1N	13	2	133	266	133	266	100	200
H-53D/E	40	5	317	1585	317	1585	215	1075
AH-1	2	1	230	230	230	230	180	180
E-2C	5	4	85	340	85	340	85	340
C-2	32	4	38	152	38	152	38	152
P-3	24	3	276	828	276	828	276	828
C-12	8	1	89	89	89	89	89	89
T-44	8	1	55	55	55	55	55	55
CT-39	8	1	17	17	17	17	17	17
E-6	22	3	16	48	16	48	16	48
C-130	97	0	108	0	108	0	108	0
V-22	26	4	0	0	0	0	55	220
TOTAL NUMBER OF RAFTS REQUIRED				5334		5377		4486

incorporate viewing ports, a water collection system, and exterior holders for signaling devices. The fabric used to construct this assembly would be light colored, and insulated. In addition the canopy:

1. Must be packaged or attached to raft
2. Capable of withstanding 35 knot sustained winds and 52 knot gusts and supply adequate headroom.
3. Incorporate two opening 180° apart with means to make them watertight

Floor

The floor should be integral to the MPLR design providing an insulation barrier for protection from a 45°F water temperature and dry seating with a water depth in the raft of 2 inches.

Capsize Resistance –

The MPLR should employ water pockets or other means to provide capsize resistance for an empty or lightly loaded life raft.

Interior and Exterior Holding Straps –

The MPLR would be required to contain sufficient straps for all occupants to restrain themselves in moderate seas. In addition, exterior straps must completely surround the raft.

Boarding Stations and Aids

Two boarding stations would be required on opposite sides of the raft: one, which could be easily utilized by an injured person with the use of one arm and:

1. Provided at opposite positions of the raft
2. Permit unassisted entry from the water
3. Must not impair the rigidity or the inflation characteristics of the raft
4. Puncturing of an inflatable boarding aid must not affect the raft buoyancy chambers
5. Stirrups and/or handles must withstand a pull of 500 lbs.

Ballast System

1. Automatically Deployed
2. Rapid Activation (Filling)

Lifeline

A non-rotting lifeline of contrasting color and at least 3/8-inch diameter on the periphery so that it can be easily grasped by persons in the water should

1. Be capable of withstanding a load of 500 lbs.
2. Not interfere with raft inflation

Graspline

1. Meet the same size and strength requirements as the lifeline.
2. Provide sufficient slack so that raft occupants can steady themselves when seated in the raft deck with their backs to the main flotation tube.

Sea Anchor

A self-deploying sea anchor should provide adequate stabilization and limit drifting in moderate sea states.

Righting Aids

Provide means for one person to right the raft in the event that it is inflated inverted.

Color

Surfaces including canopy, to improve visibility from the air must be International orange-yellow or equivalent high visibility color.

Placards

1. Contrasting colors, waterproof, not detrimental to fabric, denotes use and location of inflation system, raft equipment, boarding aids, and righting aids.
2. Letters at least 2 inches high with details smaller

Lights

1. Two or more survivor lights should be provided that are approved under TSO-C85.
2. Lights should be automatically activated and visible from any direction by persons in the water.

Accessory Pack

An accessory pack containing time-limited survival items will be mounted in such a fashion as to permit access without violating the raft reduced volume packing.

Metallic Parts

All parts must be made of corrosion resistant material or must be suitably protected against corrosion. They must be capable of remaining in operating condition for the duration of inspection cycle (5 years) of the MPLR without requiring any maintenance action. They may require maintenance at the inspection cycle prior to returning to service

Non-metallic Materials

All non-metallic parts shall be clean and free from defects that would affect function. They must be capable of remaining in a reduced volume packed state while remaining in operating condition for the duration of inspection cycle (5 years) of the MPLR without requiring any maintenance action. They may require maintenance at the inspection cycle prior to returning to service

Coated Fabrics and Webbing

A lightweight synthetic-based (e.g. polyurethane) single or double-coated material capable of meeting MIL-C-23070 strength requirements and rupture-leakage-repair would be required. This material shall be conducive to heat sealing, it will be tear resistant, and it will exhibit the minimum characteristics.

MONETARY BENEFITS

With the newer MPLR significant monetary savings are possible in four areas.

1. Potential to extend scheduled maintenance cycles from the current 224 days to 60 months resulting in an 85% reduction in associated inspection costs.
2. Returning the MPLRs to commercial source for inspection and repacking would eliminate the need to support an intermediate maintenance capability could result in savings in manpower, support equipment, training and facilities.
3. Logistical saving by reducing the number of MPLRs could reduce the associated costs.
4. Replacement of numerous single-person rafts with one multi-person raft could also reduce the initial costs.

POTENTIAL DEPLOYMENT SYSTEMS

Although not part of this program, what is most needed to ensure multi-person life raft deployment is an external mounting system that incorporates an automatic deployment capability. This system would, also, include a manual release capability for the pilots/aircrew. Commercial helicopters servicing the oil platforms in the North Sea are currently using variations of these systems. The potential for incorporation of this raft into a deployment system is being investigated.

CONCLUSIONS

By focusing on current life raft design and construction techniques with lighter, stronger, more resilient materials the Navy can provide its aircrew with a state-of-the-art life raft that can be externally mounted or stored in the restricted interior spaces of today's' aircraft.

REFERENCES

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BIOGRAPHIES

George F. Loeslein, Jr. After receiving his Engineering degree from North Carolina State University, Mr. Loeslein completed the Naval flight program and was designated a Naval Aviator.. During his Naval career he has logged over 5,000 hours in both rotary and fixed wing aircraft and served in numerous billets in operations, training, maintenance and safety within the aviation community. After retiring from the Navy, Mr. Loeslein joined Flight Dynamics and Safety, Inc. as a systems engineer and member of the Advanced Crashworthy Aircrew Survival Systems team. He entered government service in 1998 and is a member of the Integrated Test Team for the V-22, Osprey, Aircraft. He has co-authored papers on helicopter mishap trends analysis for the AH-1, H-1. H-46, H-53, H-3 and H-60. is employed at the Naval Air Warfare Center, Aircraft Division in Patuxent River, MD as a member of the Integrated Test Team for the V-22 Osprey.

Charles R. O'Rourke During his Naval careers as a Senior Chief Aircrew Survival/Parachute Rigger, Mr. O'Rourke served as Aviation Warfare Specialist, Water Survival Instructor, Naval Aircrewman aboard both fixed and rotary wing aircraft. He has over 30 years after s experience in aviators' safety and survival equipment and was a member of Naval Air Systems Command "Failsafe" Team. Since retiring from Naval service, Mr. O'Rourke is employed by the Naval Air Warfare Center, Aircraft Division in Patuxent River as an Engineering Technician at the Crew Systems Engineering Directorate. He currently the leader for the underwater egress and escape team for the Advanced Crashworthy Aircrew Survival Systems team.

Lawrence E. Kinker is presently responsible for systems technology at Flight Dynamics and Safety Inc. His B.S. degree in Chemistry is from the University of Missouri (Columbia). His experience has been primarily in the test and evaluation of escape system decision; live subject testing on the Naval Air Warfare Center, Aircraft Division, Warminster ejection tower; and field investigations among pilots and aircrew who operate fixed and rotary wing aircraft. In addition, Mr. Kinker was a U.S. Navy Active and Fleet Reserve helicopter pilot for 20 years.

The Abysmal Performance of the Inflatable Liferaft in Helicopter Ditchings

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Introduction of the liferaft into fixed wing aircraft

The inflatable liferaft or dinghy was introduced into aircraft in the 1930s. The Royal Navy Fleet Air Arm and the Royal Canadian Air Force (23) suspended it between the longerons at the aft end of the biplane fuselage (Fig 1). Just prior to World War II, the free-floating multi-seat dinghy was added to the inventory of aviation lifesaving equipment (27). Llano (22) reviewed 35% of the 4 - 5000 ditchings in World War II and the Korean War. He concluded that the liferaft had been of great value, but in virtually every case there was reference to a struggle to get into it. This was only made worse if the crewmember was injured or simply exhausted. Many survivors recommended deflating the liferaft before entry and/or climbing into an uninflated liferaft before inflating it.

In 1965, Townsend (28) reviewed inflatable liferaft performance in commercial fixed wing aircraft accidents and concluded that often the installation of life support equipment had been done as an after-thought when the rest of the aircraft design had been completed, and in many cases, imperfect installation had not improved survival. There are many similar comparisons with introduction of the inflatable liferaft into helicopters post World War II.

Introduction of the liferaft into rotary wing craft

Post WWII, once the helicopter became proven and reliable, military organizations commenced to fly them over water. There have been a steady number of ditchings but the Boards of Inquiry appear to have paid little attention to trends, good or bad, in the performance

Figure 1 – Liferaft suspended at the aft end of the biplane fuselage

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Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

of the inflatable liferaft, and until the 1990s there does not appear to have been any formal publications on their performance. With the offshore oil industry boom in the early 1970s, there was a rapid increase in the use of the helicopter to do short trips over water for servicing the rigs and transfer of crew. They also experienced ditchings and problems with the liferaft became public. In 1984, Anton (4) completed the first review of the performance of the liferaft in seven survivable commercial helicopter accidents in the North Sea. He confirmed the worst fears expressed by Townsend. Such problems with stowage of the liferaft not close to exits in the fuselage; poor engineering designs for quick deployment; difficulty with securing the raft to the fuselage; little protection from puncture; poor design causing difficulty with entry. Like introduction into fixed wing aircraft, introduction into the helicopter had come as an afterthought to the original helicopter design. In addition, the training of aircrew was poor and virtually non-existent for passengers.

A brief review of the success/failure of launching is presented in Table 1.

Even after the liferafts were launched, Anton reported on a "rather gloomy picture" and this is presented in Table 2. Thus in only one (G-BEID) of the seven accidents did the liferaft perform as specified, and even in this case it was difficult to retain it to the side of the helicopter for boarding.

In 1984, the Civil Aviation Authority (26) produced 40 recommendations from the Helicopter Airworthiness Review Panel (HARP) for improving helicopter safety. This included improvements to boarding ramps in liferafts, protection from puncture and recommendations to remove external protuberances from helicopter fuselages that could snag or damage the raft.

The four U.K. helicopter operators (Bristow, Bond, B.A.H. and B. Cal.) collaborated with RFD Aviation and produced a new liferaft (19). The great advantage of the new Heliraft is reversibility, the inflated fender tube that becomes the structure for the canopy, the ease of entry and rescue from, and compartmentability in case of puncture. The entire North Sea Fleet of 150 helicopters was fitted out with the Heliraft by the end of 1995 which was no mean feat.

Liferaft performance in helicopter ditchings subsequent to 1983

In 1994, Brooks reviewed the Canadian Air Force water survival statistics for the previous 20 years (7). Out of the nine helicopter accidents, there were three Sea King accidents where problems were noted. In one case, the helicopter rolled over on top of the six-man liferaft and rendered it useless; in one case it was difficult to launch the multi-placed raft; and, in one case, it was impossible to launch at all. In one of these three cases, it was reported that all the crew had difficulty boarding the raft.

LIFERAFT DEPLOYMENT Courtesy of Dr. D.J. Anton	
G-ASNM	Difficult to launch due to weight and small exit
G-AZNE	Pilot chose to swim to ship rather than to attempt to release liferaft, helicopter sank rapidly
G-ATSC	Launched by passengers
G-BBHN	Unable to deploy due to inversion and raft trapped
G-BEID	Deployed by crew, difficult to retain against side of helicopter
G-BIJF	Liferaft broke free from mountings. Not used.
G-ASNL	Both liferafts launched by crew

Table 1

LIFERAFT DAMAGE Courtesy of Dr. D.J. Anton	
G-ASNM	Punctured by contact with tail rotor. Upper compartment deflated, canopy would not erect
G-ATSC	Liferaft boarded prematurely. Boarding passengers interfered with correct inflation. Unable to top up due to lack of correct adapters. Tear in side of liferaft, plugged with leak stoppers
G-ASNL	Both liferafts punctured by contact with aircraft

Table 2

In 1995, the Cord Group (14) completed a retrospective examination of helicopter liferaft performance in a mixture of civilian and military up until 1995 for the National Energy Board of Canada. This is quoted in toto.

In May 1984, a Boeing Vertol G-BISO (16) was enroute to Aberdeen from the East Shetland Basin with a full load of 44 passengers and three crew. Following a flight control system malfunction, it ditched eight miles north west of the Cormorant Alpha Rig and capsized 82 minutes after touchdown. The First Officer turned the aircraft 40° to the right of the wind to see if this would provide better conditions for launching the liferafts from the right side. However, the aircraft started to roll an estimated ± 10° and the blades could be seen disturbing the water as they passed close by. The aircraft was turned back into the wind. All crew and passengers evacuated successfully. The first liferaft had been launched through the forward right ditching exit with the painter secured around the arm of one of the passenger seats. After some passengers had entered the liferaft through the forward right exit it was either dragged or blown out of reach. More passengers went through the rear right exit and clambered forward along the top of the sponson in order to reach the liferaft. Approximately nine passengers had boarded when the painter parted allowing the liferaft to drift behind the aircraft. The second liferaft was also launched through the forward right exit and the painter similarly secured. Two passengers had entered this liferaft when its painter also parted and one and one-half hours later both rafts had drifted clear of the aircraft. Approximately 10 minutes later, the remaining passengers escaped through the rear right exit into the water and drifted behind the aircraft where they were picked up either by surface vessels or by one of three rescue vessels.

In March 1985, an S61 helicopter enroute from the offshore oilrig SEDCO 709 to Halifax airport ditched following loss of transmission oil pressure (11). All 17 occupants boarded two liferafts, but most consider themselves very lucky that they survived. It was a calm day and the sea state was also calm. The following day, there was a raging blizzard and no aircraft flew offshore. The narrative reads as follows: *"After the pilot in command had shut down the helicopter engines and stopped the rotor, he moved aft to the passenger cabin. Once he had passed the airframe mounted ELT to the passengers, the liferaft was pushed away from the helicopter. As the raft moved into the outer limit of the rotor arc, the rotor blades were striking the water dangerously close to the raft and the occupants had difficulty keeping the raft from being struck by the rotor blades. After launching the No. 1 liferaft, the pilot, co-pilot and remaining passengers inflated the No. 2 liferaft beside the aircraft and stepped directly into it. The raft was then pushed away from the helicopter and it drifted under the tail pylon. The three occupants had difficulty keeping the raft clear of the stationery tail rotor blades as the helicopter was pitching and rolling in the water. The No. 1 liferaft had a 4-inch tear from rubbing against helo and as a result, the lower buoyancy chamber deflated. By the time the rescue helicopter arrived, the occupants were sitting in 18 inches of water."*

In 1987, the E. and P. Forum reviewed two accidents (17). The first was a Bell 214ST helicopter (G-BKEN) that made a controlled ditching into the sea 16 miles North of Rosehearty, Scotland (15 May 1986). Eighteen passengers and two crewmembers successfully transferred to two liferafts. The second accident occurred in December 1986 and was just survivable. In this case, a Puma 330J flew into the sea off Western Australia, it overturned rapidly and sank, and no liferafts were deployed. Thirteen of the fifteen crew and passengers escaped and were rescued from the sea. This latter accident emphasized the point that in a poorly controlled ditching or ditching in very turbulent water, the likelihood of deploying liferafts, which are stowed within the fuselage, is virtually impossible (8). Moreover, if the helicopter is inverted and flooded, no one can proceed backwards underwater to release the liferaft from its stowage.

In March 1988, a Bell 214ST helicopter (VH-LAO) (6) ditched off Darwin Australia rapidly flooded and inverted. The two 12-man liferafts, which can be released by the pilots from the console in the cockpit, were not deployed because the rotor blades were still turning. It was too late and not possible to do it later with the rapid flooding and inversion. So, 15 passengers and crew evacuated into the sea. The crew then decided to duck dive into the fuselage to get one raft out. After several attempts, this was successful. After it was inflated, five to six survivors got onboard, then the bottom flotation tube was punctured by contact with one of the helicopter doors. The raft then partially filled up with a mixture of seawater and Avtur making everyone violently sick from the fumes. The raft could accommodate no more than six survivors in this punctured condition. The rest of the survivors remained in the sea for approximately one hour and ten minutes before rescue.

In October 1988, while on a SAR mission off the northwest coast of Scotland, the pilot of a S61N helicopter G-BD11 became disoriented, and the helicopter struck the sea and immediately rolled over (1). The liferaft inflated as advertised, but the boarding ramp was very slow to inflate, rendering it useless at the critical time that it was needed. Once on board, it needed the combined effort of the four survivors to free the canopy from its stowage. An analysis following the accident revealed that an incorrect procedure had been conducted, and that the painter line should have been cut before attempting the canopy erection.

On November 1988, an S61N helicopter (G-BDES) was tasked on a non-scheduled public transport service from Aberdeen to three oil installations (15). On return to Aberdeen, it suffered a sudden loss of main transmission oil pressure and the pilot had to ditch ninety miles North East of Aberdeen. The two pilots and four passengers scrambled onboard the first liferaft after activating the external release lever, but the remaining seven passengers were unable to reach or deploy any liferaft; they spent 41 minutes in the sea before rescue. The co-pilot in the raft had to fend it off from an aerial and the tail rotor which both came close to puncturing it.

In 1989, the E and P Forum reviewed a further three more accidents (18). The first was a S61N helicopter (G-BEID) enroute from the "Safe Felicia" in July 1988 that did a controlled ditching off Sumburgh, Scotland. With rotors fully run down, the forward cabin passengers egressed with no problem, but the passengers in the rear cabin had difficulty launching and boarding their liferaft. Ultimately, two crew and nineteen passengers were rescued.

The second accident was a Super Puma (LN-OMC) that ditched in the North Sea also in July 1988 and floated for ten minutes. The first liferaft was blown by the wind against the fuselage and rendered useless. All 18 passengers and crew evacuated into the second liferaft.

The third accident was a Bell 206 EI that ditched in February 1987 into the Gulf of Mexico in a six to eight foot sea. The sharp corner of the front door punctured the liferaft rendering it useless. The pilot and passenger remained onboard until rescued by boat.

In 1989, Reader (25) published the British military experience with 94 helicopter ditchings for 1972 to 1988. He reported that the biggest problems with safety equipment in order of frequency were:

(a) problems with liferaft inflation;
(b) inadequate seat belt restraint; and
(c) loss of a liferaft.

There were ten accidents where he specifically cited difficulty with liferafts (Sea King - 4; Wessex - 5 and Wasp - 1) and in a further seven

Sea King accidents, he noted that all the liferafts were lost.

In November 1991, a Bell 214ST (VH-HOQ) with fifteen passengers onboard departed the Skua Venture helipad for Troughton Island, Australia but through mechanical problems had to ditch barely twenty feet above the pad (5). The pilot made a controlled water landing and deployed flotation bags. The co-pilot activated the two liferafts, which were both launched. However, only the starboard one cleared the floats and inflated. The port liferaft slid into the water and did not inflate automatically. One of the survivors while still in the fuselage pulled on the liferaft painter and inflated it. Whereupon the 17 crew and passengers evacuated into the two rafts. At this point, the starboard float burst, the helicopter rolled over and the rotor blades came down on top of the starboard liferaft. The Lady Cynthia's rescue boat came to the rescue and towed the liferaft clear of the blades before rescuing the survivors.

In March 1992, a Super Puma (G-TIGH) shuttling 15 passengers from the Cormorant Alpha platform to the accommodation vessel "Safe Supporter" 200 hundred metres away crashed into the sea only 47 seconds after lift-off (2). The liferaft in the right cabin door was released from its stowage, shortly after the door had opened on impact, the inflation probably being initiated by the short painter. It suffered major damage. It did, however, inflate at least partially and provide support for possibly six personnel. Because it was so badly damaged, it was extremely unstable in the water and overturned on several occasions. The second liferaft, under Seats No 5 and No 6 adjacent to the left cabin door, was not deployed. One crew and ten passengers perished. This precipitated a further examination by the C.A.A. of helicopter offshore safety.

In 1993, the F.A.A. (12, 24) published two reports on 77 rotorcraft ditchings between 1982 and 1989. The National Transportation Safety Board investigated 67 of them and the U.S. Army investigated the remainder. In the first report, there was only a small observation section on the availability, use and performance of person flotation equipment. The details on the performance of liferafts were very scant. Out of a total number of 204 occupants, 111 used some form of personal flotation device and only 24 made use of a liferaft. Of this number, 23 occupants used a liferaft. The overall summary was that in the cases studied, the people did not generally use liferafts. In the second report, the findings were as follows: *"Liferafts stored near the chin bubble are often lost when water flows out the chin bubble. The rapid overturning of the rotorcraft requires occupants to egress immediately rather than locate the liferaft then egress. The effects of wave action on the floating helicopter often precludes re-entry for the purpose of extracting the liferaft. Re-entry is not advisable with current systems because of the frequency of delayed separation of the floats from the rotorcraft. Access to the liferaft should be improved in the common event of the overturned helicopter. Locations to consider include exterior of the rotorcraft, exterior access panels, near the rotorcraft floor by an exit and integrated with the flotation system."*

In March 1995, a Super Puma helicopter (G-TIGK) enroute to the East Brae production platform experienced a tail rotor lightening strike and the pilot conducted an immediate ditching (3). The 16 passengers and two crewmembers made a miraculous escape into one liferaft. Unfortunately, the second liferaft was deployed and blew up against the side of the fuselage and was rendered useless. Also in 1995, a Bell 214ST helicopter ditched in the Timor Sea and immediately rolled over. There were just two pilots onboard who egressed safely, but one had to dive back into the fuselage to release the liferafts.

Finally for 1995, the Civil Aviation Authority (13) published their review of helicopter offshore safety and survival. The findings related to the liferaft were:
"As a result of previous shortcomings in the performance of liferafts carried in helicopters, the new 'Heliraft' was developed in 1985 and is now in service throughout the offshore fleet. Its reversible design is based upon a double inflatable ring with a floor sandwiched between and a hood, which can be erected on either side, with all equipment and attachments duplicated; it thus avoids the problem of accidental damage (as was demonstrated in the Cormorant Alpha accident), is of a size and

weight that permits it to be handled by one person in reasonable wind and sea states, and is more readily boardable by survivors from the sea by means of a ramp and straps."

Progress post-1995

When a helicopter ditches and the crew and passengers have a matter of a minute to make a decision, they have four options how to evacuate the fuselage into the liferaft. The first choice is on which side to abandon the helicopter, the leeward or the windward side. Attitude and direction that the helicopter has landed on the water during the accident may have predetermined this choice. Exiting from the leeward side causes more difficulties with clearing the liferaft from the fuselage and the strike envelope of the blade because the helicopter will drift quicker than the human can paddle, whereas exiting on the windward side causes more likelihood of the liferaft being blown up against the side of the fuselage and difficulty with keeping it close to the side for entry.

The second choice is whether to inflate the liferaft immediately on launching and wait the critical 30 seconds for full inflation prior to boarding in a dry condition (dry shod or dry method), or to launch the liferaft in its package using the first survivor out to swim it clear of the strike envelope prior to inflation, each subsequent survivor swims out along the painter to join the first one out (wet shod or wet method).

Because no formal scientific evaluation had been completed on the problem, the National Energy Board of Canada tasked the CORD Group to evaluate the current training standards, the direction of evacuation and the two techniques for inflation, the dry method or wet method. The first experiment conducted using the Nutec Super Puma helicopter simulator in the Bergen Fjord (9, 14) recommended that the dry method be taught as the method of choice. The wet method should be taught as an alternative method in case there is no time to wait for the liferaft to inflate and the helicopter is potentially about to capsize. Evacuation, wherever possible, should be conducted on the windward side and that pilots required more realistic training than simple wet dingy drill in the swimming pool.

A second series of experiments (10) were conducted to increase the subject data pool from the first experiment and to evaluate the advantages and disadvantages of using both the traditional aviation liferaft and the new RFD Heliraft. The original findings from the first experiment were confirmed. In addition, it was concluded that the Heliraft had many distinct advantages over the traditional raft: it was reversible and needed no righting and it was far easier to enter from the pitching helicopter. It was noted that both styles of liferaft needed relocation of the painter to insure the liferaft hauls up tight to the fuselage without the boarding ramps in the way. Finally, in order to assist training of aircrew, a ditching survival compass (Fig 2) was designed for decision making as to which side of the helicopter and which method of evacuation should be used.

In January 1996, the Norwegians had a Super Puma LN-ODP accident into the North Sea (20). In four metre seas, the crew first deployed the starboard liferaft on the windward side where it was blown on its side up against the fuselage. The crew then decided to deploy the second liferaft on the port side. This liferaft was launched on the leeward side and a dry evacuation was attempted. It was impossible to paddle the liferaft clear of the fuselage because the helicopter drifted faster than the survivors could paddle. As a result, the liferaft was struck by the tail rotor, was punctured and sank. Those already in the raft then swam back to the still floating helicopter (one passenger nearly drowned when pushed underwater by the tailskid). Once back in the fuselage and after much effort, the pilots forced the original starboard liferaft down onto the water, but in the process of cutting the entangled sea anchor, inadvertently cut the painter. As a result, the survivors nearest to the door did not have the strength to hold it in position close to the fuselage because the helicopter was drifting faster than the liferaft; only three survivors and one pilot were able to get into it before it drifted clear on the windward side. The personnel in the liferaft were hoisted by a rescue helicopter before the remaining pilot and 13 passengers were hoisted from the floating fuselage 50 minutes after ditching.

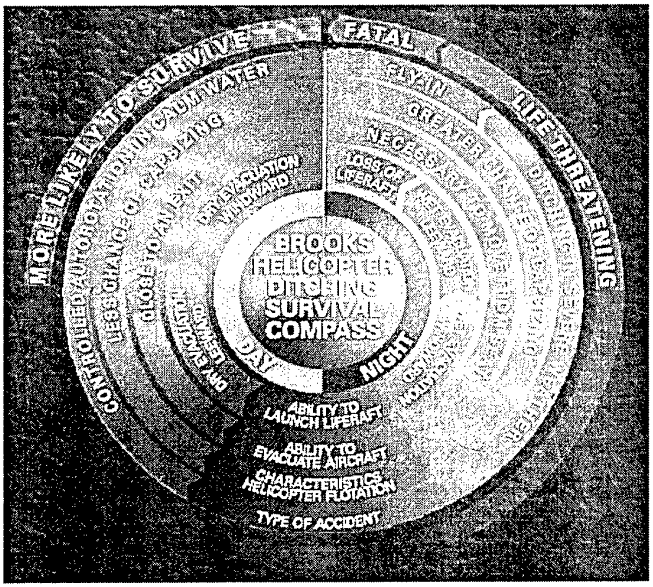

Figure 2 – Brooks' Helicopter Ditching Survival Compass

In 1996 Kinker et al (21), completed an analysis of the performance of US Naval and Marine Corps liferaft performance over a 19-year period. Mishaps involving the AH-1, UH-1, H-46, H-53 and H-60 helicopters were studied between 1977 and 1995. They also confirmed the poor performance of the liferaft. In only 26% of the 67 survivable over-water accidents was the liferaft deployed. They further concluded that for the last 20 years there has been a unique and dangerous circumstances surrounding raft accessibility and helicopter egress which had not been addressed. Liferafts were too large and cumbersome, not only to lift, but to fit through emergency exits; they were inaccessible for rapid launching and often positioned 10 to 15 feet from visible exits; and, even if launched, in the case of the multiplaced raft, often float several feet underwater before inflation (if the inflation ring has not been pulled), so making locating the raft difficult.

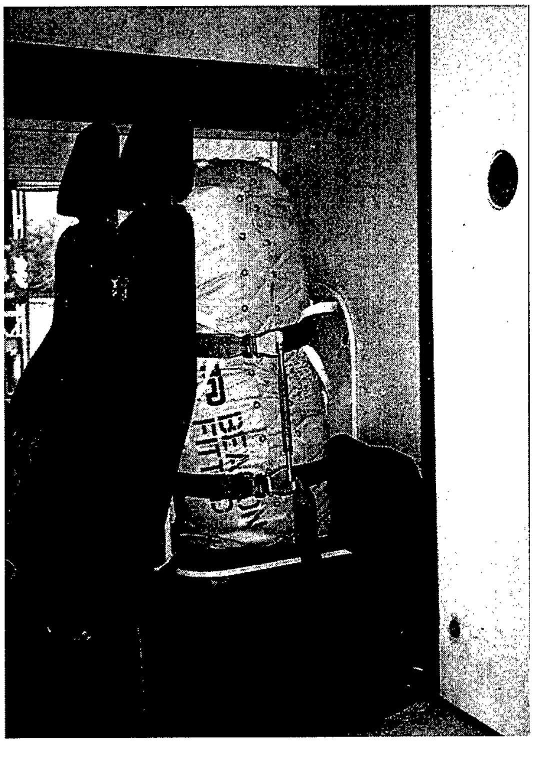

Figure 3 – A typical position for the multi-seat liferaft placed behind the forward bulkhead on the port side aft of the pilot in the Sikorsky S61N

Discussion

A literature review of the performance of the aviation liferaft in helicopter ditchings has been presented. Records just post-war are scant, but in the last 20 years more complete. It is clear from the more recent civilian and military data that a modified inflatable marine raft has simply been fitted into the cockpit and/or fuselage of the helicopter as an after-thought following the design of the helicopter.

Thirteen years ago, the first purpose built helicopter aviation raft was put into service. This has only partially solved the problem because there has been no regard for the human dynamics involved in the requirement for split second decisions in the ditching process, and the problem with difficulty with boarding is just as serious as it was when the original marine inflatable life raft was introduced 60 years ago!

In 50% of accidents, the helicopter will capsize and sink rapidly and, in the remainder of the cases, balance precariously on the water surface. The crew and passengers are thus faced with imminently drowning from in-rushing water. This is compounded by disorientation from inversion and inability to see underwater, inability to locate levers to jettison doors and hatches and worst of all, a 50% reduction in breath holding ability in water below 15°C. There is no time left for them to locate a liferaft, struggle to manoeuvre it to an exit, which is often at some distance away, heave it out and wait for inflation. Even when it is inflated, it is not easy to board or be rescued from, and while tethered to the helicopter runs the serious risk of puncture from sharp edges on the fuselage or a blade strike. There is now growing evidence to support these comments.

Anton's series reported only one out of seven accidents where the liferaft worked as advertised. Brooks and Reader both reported problems with Canadian and British military liferaft deployments. The data presented in this paper of 15 civilian helicopter accidents between 1984 and 1996 shows that only one accident in which the liferafts worked as specified; and finally Kinker and his colleagues published the USN/Marine data over the last 19 years where the liferaft was utilized only 26% of the time.

Considering the rapid advance in technology for the helicopter engines and airframes, the life support systems have not only lagged behind by 40 years, but in recent years have not been considered in the fundamental design of new airframes. Two approaches should be taken, first consideration be given to keeping the helicopter or a portion afloat and using this as the primary safe haven for the crew and passengers from drowning and hypothermia (and there has been some preliminary work on this); however, this does not solve the problem of the fly-in where a liferaft is necessary or for capsizing in heavy sea states. In this case, a whole new concept is required to design a person-mounted liferaft that may incorporate personal flotation and hypothermia protection, and most important of all be easy to board, and be strong enough to resist puncture. NATO countries, in conjunction with helicopter manufacturers and human factors research laboratories, should jointly fund such a programme.

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Utilization of Medical Support Equipment on Board Army Rotary-Wing Aircraft

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SUMMARY

The U.S. Army Airworthiness Certification and Evaluation (ACE) program at the U.S. Army Aeromedical Research Laboratory (USAARL) is designed to evaluate medical life support equipment for compatibility within the rotary-wing aviation or medical evacuation (MEDEVAC) environment. The program goes beyond any prior validation of medical equipment for use within the controlled hospital environment, and assesses the equipment in the context of the military environment, from the supply and distribution chain, through storage and use in field conditions. The end product is an assessment that assures the safety of the aircraft and its subsystems, the aircraft crew, the device itself, and ultimately, the patient. Since the program's inception in 1983, standards have evolved to better reflect the actual rotary-wing operational environment [1]. This evolution challenges manufacturers striving to produce viable products to meet both hospital and in-flight requirements in the military and civilian sectors.

From July 1992 to August 1998, 24 medical devices including monitor/defibrillators, infusion pumps, vital-signs monitors, and ventilators were tested under specified conditions of temperature, humidity, altitude and vibration (MIL-STD-810D and 810E) [2]. Electromagnetic emissions and susceptibility were measured (MIL-STD-461C, 461D) [3], and human factors (MIL-STD-1472D) [4] were evaluated. The devices were flight tested in the USAARL JUH-60A MEDEVAC helicopter. Thirty-two percent of the medical devices failed at least one environmental test. Ninety-one percent of the devices failed to meet the 461C and 461D standards. Only three devices were tested at the new 200 V/m radiated susceptibility level, but all failed. Failures included excessive conducted and radiated emissions and susceptibility to radiated emissions.

SUBJECT MATTER KEY WORDS

air medical transport
electromagnetic interference
high intensity radiated fields (HIRF)
medical evacuation (MEDEVAC)
medical equipment
safety

1. INTRODUCTION

U.S. Army MEDEVAC operations are conducted 24 hours a day in all weather conditions, and range from support of local highway accidents and basic hospital transport scenarios, to direct combat support operations conducted at various mobilization sites worldwide. Due to continuing technological advances in medical life support equipment, commercial off-the-shelf (COTS) medical equipment is now being targeted for military application. However, vendors are also being asked to design their equipment to stringent military standards and specifications as a condition of acceptance for medical equipment procurement. Considering the high costs involved with product design, testing, and re-engineering, it is understandable that industry questions each Army requirement.

2. ENVIRONMENTAL HAZARDS

"Environmental Test Methods and Engineering Guidelines" (earlier MIL-STD-810D and now MIL-STD-810E [2]) addresses standards for high and low temperatures, high humidity, altitude, and vibration for U.S. Army aeromedical equipment. Manufacturers frequently ask if these environmental standards are necessary or realistic. In most cases, commercial vendors are simply unaware that military equipment is routinely subjected to such environmental conditions. For example, a requirement for testing at 15,000 feet pressure altitude reflects Army mission requirements in an unpressurized helicopter, where mountain rescues may frequently exceed this standard. The reality of the supply system supporting the U.S. troops during the Desert Shield and Desert Storm operations is that many supplies were delivered in metal containers by ship or by air. Upon arrival, equipment frequently sat on the docks or adjacent to the airfield at Riyadh, Saudi Arabia, and was subjected to very severe environmental extremes. Delivery to receiving units ranged from days to weeks, and until the equipment was placed in service, it may have been placed in even less protected storage.

2.1 The Natural Environment

Routinely tested exposures include heat, cold, vibration, and altitude. Compared to the older MIL-STD-810D, MIL-STD-810E [2] now includes environmental exposures more reflective of actual field conditions. For example, high temperature storage was previously tested at 71°C, 15% relative humidity for 6 hours; the new storage test scenario is 63°C, 15% RH for 1 hour, 71°C, 15% RH for 4 hours, and finally 63°C, 15% RH for 1 hour. This test set is repeated for seven cycles, another new requirement.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

Cold temperature testing, which simulates storage at -46°C and operation at -25°C, are controversial within the manufacturing community. Peacetime operations in Alaska, where high altitude helicopter rescue flights encounter temperatures lower than the established test criteria, illustrate the practical application. In answer to the question: "Will anyone really attempt to use a powered infusion device or ventilator at minus 25°C?," one must only look at the cold-soaked helicopter cabin on the "standby ramp," with limited heating en route and no heating at all once the doors are opened at a high hover during a rescue hoist operation. Fluid transfer is not realistic at minus 25°C, but at the same time, the medical equipment must perform its designed function once the cabin doors are closed and a rewarming process allows life support to begin. The U.S. Army UH-60Q MEDEVAC helicopter incorporates an on-board oxygen generation system, suction system, external rescue hoist, and litter lift system with plug-in power provisions for carry-on medical equipment within the aircraft (Figure 1). MIL-STD-810E storage and operational requirements are being used as acceptance criteria for this airframe subsystem. In the vibration domain, on the other hand, USAARL has requested a waiver from the U.S. Army Aviation and Missile Command (AMCOM) for reductions in intensities and duration for certain vibration criteria in the new standard. This pending request is based on vibration signatures USAARL researchers obtained from actual in-flight floor measurement data in the JUH-60 helicopter. Altitude testing requirements, referred to above, remain unchanged in MIL-STD-810E.

Figure 1. UH-60 Q MEDEVAC Helicopter onboard oxygen generation, suction, rescue hoist, automated litter lift/tilt system, & power supply for additional carry on equipment.

2.2 The Electronic Environment

Electromagnetic interference and compatibility were first recognized as problems by the Army during World War II, when radio communications were degraded by ground vehicle ignition systems. As the complexity of military systems has evolved, so have our concerns in this arena. Conducted and radiated emissions of medical equipment may interfere with the aircraft and its subsystems. Conversely, the aircraft may interfere with the medical equipment under test (EUT). Electronic fields existing outside the aircraft are becoming more critical throughout aviation, especially in rotary-wing operations. Mechanical linkages and analog systems are being replaced with fly-by-wire and digital systems. Even within the limited realm of individual medical support devices, compatibility is an issue when many of these devices are combined for use in a single system, such as the Army Life Support for Trauma and Transport (LSTAT) [Figure 2]. This self-contained litter system is integrating total system management via an internal electrical power subsystem. LSTAT components such as the ventilator system, environmental control subsystem, oxygen delivery system, defibrillator, IV/drug delivery system, suction system, physiological monitoring system, clinical analyzer, display and data logging [5], each carry individual challenges for electromagnetic interference (EMI) and electromagnetic compatibility (EMC), as well as collective integration interface compatibility issues.

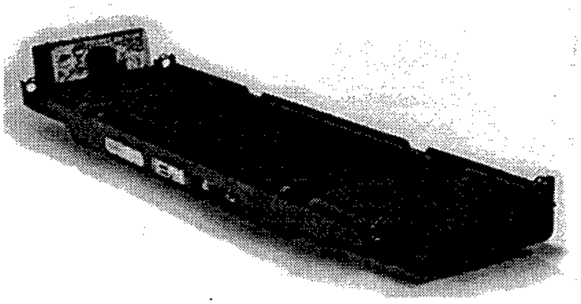

Figure 1. Life Support for Trauma and Transport (LSTAT) integration of 11 sub elements/systems.

The use of integrated and miniaturized circuits with higher densities and increased data flow also increase the threat of susceptibility to external offenders such as High Intensity Radiated Fields (HIRF) [6]. These fields are created by various types of radio transmitters and radar systems [7]. HIRF intensities vary with frequency; with early HIRF worst case peaks defined by the FAA as 1,000 V/m up to 1 GHz, and up to 17,000 V/m above this level. Peak International Certification Environments defined for EMC testing of whole aircraft were charted by Carter and Bull in 1994 [8]. The energy levels varied between 50 V/m at .01 MHz to 100 V/m at 2 MHz, and up to 7,000 V/m at 4 GHz. One example of an unclassified HIRF site is Otis Air Force Station, Massachusetts, which was used with the cooperation of the FAA during a helicopter flight test.. This radar transmitter operated between 400 and 800 MHz, with sweeps from 22,000 ft to 54,000 ft high with an azimuth spread of 240°, operating from a hill approximately 100 ft above the surrounding coast line [7]. Table 1 illustrates that a 203 V/m field can be encountered as far as 1 statute mile from the site; an aircraft that flies within 1/4 mile will encounter an electronic field of 813 V/m. At linear distance of 10 miles, the strength diminishes to a field of 20 V/m, which is the energy level that failed 44% of the 34 medical devices tested during the period January 1989 through June 1992 at USAARL under the old MIL-STD-461C criteria. The new MIL-STD-461D [3] RS103 test requires an additional 200 V/m test across the frequency ranges 10 kHz to 18 GHz.

The ACE program addresses two very basic issues: First, does the medical device interfere with vehicle systems in a way that could compromise safety? In one case, activating a suction pump caused deviations in the magnetic compass; switching on another device produced indications of lightning on the aircraft's weather radar. Second, do vehicle systems interfere with the medical device? For example, a particular environmental factor (e.g., a HIRF emitter) could cause a ventilator, suction pump, or infusion pump to pause for a few seconds (not a critical danger to the patient), or the result could be a total failure of the device or a failure requiring a restart or reprogramming of the device (dangerous and unsatisfactory). Since 1992, USAARL assessments are categorized in accordance with a standardized risk assessment matrix of MIL-STD-882C [9], which covers system safety design requirements, integration, evaluation, compliance and verification.

The large openings in the rotary-wing airframe that form the cockpit windscreens, overhead and side windows, and "chin bubbles" have been main entry route for external electromagnetic energy penetration of the helicopter cabin. Cabin windows in fixed-wing aircraft are tiny by comparison. Additionally, modern military helicopters are using more composite materials in comparison to the traditional aluminum designs of large fixed wing transports. The clear advantages in weight and strength of composites have an associated cost in comparatively less shielding for HIRF consideration [10]. Finally, civil and military helicopters alike tend to operate in a transmitter-rich environment where radiation exposure is a function of altitude and exposure duration[11]. These factors combine to make a strong case for a separate rotary-wing standard for HIRF exposure [12]. The International Civil Aviation Organization (ICAO) establishes operating rules for HIRF operations, clearly recognizing an increased threat from these hazards, but specifically excludes rules for rotorcraft [13]. Although there have been no direct examples of EMI-associated failure of medical equipment during in flight operations, the USAARL in-flight testing program has identified direct failure modes associated with frequencies normally used in aviation operations. Anecdotal information directly relates to HIRF interference on a much larger scale[14]. One such anecdote refers to an airship flying over a specific radio transmitter in North Carolina. The airship, in close proximity to the radio transmitter, experienced a double engine failure, after which a successful restart was accomplished and the airship continued to a landing site. The owning organization implemented a 5-nautical mile radius "no fly zone" around the antenna, and added, "Operators should be aware that high intensity radio transmitters are not always marked on aviation charts and, therefore, should make their own research to identify all such transmitters in their operating areas."[14] Despite these published accounts, medical equipment susceptibility testing has not received a high priority, especially by users of ground-based medical systems. For example, no study has addressed the frequent proximity of military field tent hospitals to airfields, which are usually very close to powerful transmitters.

Currently, equipment being considered for procurement by the U.S. government is tested for EMC in accordance with standards established by MIL-STD-461D (Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference) and ADS-37A-PRF, (Electromagnetic Environmental Effects (E^3) Performance and Verification Requirements). MIL-STD-461D (Radiated Emissions Test 102 [RE 102]) requires 6,251 frequency steps per mode of operation of equipment. If a monitor/defibrillator, for example, operates in electrocardiogram (ECG) monitor mode and direct current (DC) mode, one test cycle would suffice. If alternate current (AC) and DC modes are desired, the test is repeated. If the defibrillator item is to be operated as an ECG and a cardiac pacing capability is added, testing is doubled again at a cost of approximately 16 days total effort. Resourcing such testing becomes financially prohibitive for smaller manufacturers attempting to solicit government contracts.

3. MATERIALS AND METHODS

The objective of this paper is to review the ACE testing of medical life support devices at USAARL between July 1992 and August 1998. Criteria for testing are set by the AMCOM while direction for testing may come through the U.S. Army Medical Command, the U.S. Army Medical Research and Materiel Command, the U.S. Army Medical Materiel Development Agency, the Defense Medical Standardization Board (DMSB), or other U.S. Department of Defense offices. The testing includes an initial inspection to determine operational modes and patient interface requirements, and an actual operational validation check prior to test. Basic human factors, electrical safety, and battery life validations are included. The environmental testing includes altitude, temperature (storage and operational), vibration, and humidity. Table 2 details the current environmental MIL-STD-810E requirements. Electromagnetic compatibility characteristics include radiated emissions emanating from the EUT, conducted emissions emanating through power leads to/from the EUT, conducted susceptibility of the EUT to inputs reflective of aircraft power supplies, and radiated susceptibility of the EUT to inputs reflective of the aviation environment such as the HIRF discussed earlier, but limited to 200V/m. Table 3 describes the current electromagnetic MIL-STD-461D requirements. After in-flight testing is conducted, final laboratory and in-flight reports are compiled. Human factors and system safety issues are addressed throughout testing, and the final report addresses these concerns in a standardized risk assessment matrix, which MEDCOM can use as background for procurement decisions.

4. RESULTS

During the study period, 24 medical devices completed laboratory and flight tests at USAARL. These included one infusion pump, three cardiac monitor/defibrillators, five blood pressure monitors, three suction pumps, one pulse oximeter, seven ventilators, and two molecular sieve oxygen generating systems.

Two devices failed the initial safety/validation check. One ventilator failed because a significant disparity in volume output was observed between battery and AC power. The unit was withdrawn and not selected for further testing by the government. Also withdrawn from initial testing was a self-contained litter system that had basic design problems. These two devices are not considered further. Table 4 lists the devices that failed the MIL-STD-810E environmental standards. The most common failure was in vibration testing where five of the devices (23%) failed. Reasons for failure included battery displacement and loss, cover security failures, inconsistent operation of the EUT, and total device failure. Over 57% of the ventilators failed at least one of the environmental tests. None of the items failed the humidity tests.

Table 5 details the devices that failed the MIL-STD-461D electromagnetic standards. The most common reason was failure to meet the various EMI/EMC criteria. Radiated emissions criteria were not met by 19 of the 22 tested devices (86%). The conducted emissions test was failed by 36%, and the radiated susceptibility test by 27%.

Results of the new 200V/m test are not included in these analyses, since only three items have been tested under this requirement and all failed the initial test. These devices (one ventilator and two cardiac monitor/defibrillators) have subsequently been re-engineered and have now met these criteria.

To date, 24 devices have begun the formal ACE laboratory testing process. Four of these devices have received limited airworthiness release for flight testing in the USAARL UH-60 and technical reports have been published. Seven of these items are currently under modification and show promise for future acceptance.

5. DISCUSSION

As military test standards evolve, the U.S. Army's ACE program evaluates medical equipment for use on-board Army MEDEVAC aircraft. These standards, for the most part, address real world operational environments that are typically not recognized, understood, or appreciated by manufacturers of civilian medical equipment. Civilian manufacturers are being asked to supply commercial off-the-shelf equipment, but are now required to meet stringent military standards prior to procurement. The greatest challenge faced by manufacturers is in the EMI/EMC arena.

The 86% failure rate in radiated emissions testing is particularly worrisome, raising the possibility that medical equipment in use today may leak electromagnetic energy that could affect the 27% of medical equipment that, in our experience, fails radiation susceptibility testing. That is, medical equipment could interfere with other nearby medical devices. As the Army develops self-contained medical support systems, such as LSTAT, and positions medical devices in close quarters, as on the UH-60Q helicopter, these issues could become problematic.

The new 200 V/m testing requirement is important to address HIRF threats, and must be addressed early in any design effort.

6. CONCLUSIONS

The operational environment of military medical devices has expanded beyond the walls of the sanitary hospital and extends to all the various medical evacuation platforms and variety of combat environments. Hazards involved in these varied applications have been identified, and standards set to assess possible equipment limitations. Personnel at all levels of military medical planning and procurement must understand the MEDEVAC environment to ensure that the life-saving equipment actually works when needed for the patient in distress.

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Table 1. Radar E-Field Levels Analysis

Radius from transmitter	E-Field (V/m)
¼	813
½	406
¾	271
1	203
5	40
10	20

Table 2. Environmental Tests and Methods.

Altitude Test	Operate device at 15,000-feet altitude equivalent for 1 hour
High Temperature Test (Operating)	Operate device at 49°C (120°F) for 2 hours, minimum 3 cycles
High-Temperature Test (Storage)	Store device at 63°C (145°F) for 1 hour, 71°C (160°F) for 4 hours, and 63° C for 1 hour, minimum 7 cycles.
Low-Temperature Test (Operating)	Operate device at -25°C (-13°F) for 2 hours, minimum 3 cycles.
Low-Temperature Test (Storage)	Store device at –46°C (-51°F) for 6 hours, minimum 7 cycles.
Vibration Test	Vibration for 1 hour in each axis with signature equivalent to helicopter environment.
Humidity Test	Operate device at 29.5°C (85°F), 95% relative humidity for 4 hours

*In accordance with MIL-STD-810E

Table 3. Electromagnetic Characteristics Tests

Maximum radiated emissions (RE)	30 Hz to 18 GHz
Tolerance to radiated susceptibility (RS)	30 Hz to 18 GHz
Maximum conducted to emissions (CE)	30 Hz to 10 MHz
Tolerance to conducted susceptibility (CS)	30 Hz to 400 MHz

*In accordance with MIL-STD-461D, MIL-STD-462D, and ADS-37A-PRF

Table 4. Number and Percentage of Medical Devices Failing Individual Environmental Tests
(Exclusive of two items failing initial inspection).

Type of Device	Altitude	High Temp	Low Temp	Humidity	Vibration
Infusion pump (n=1)	0	0	1 (100%)	0	0
Monitor/defibrillator (n=3)	0	0	0	0	0
Blood pressure monitor (n=5)	1 (20%)	2 (40%)	0	0	1 (20%)
Suction pump (n=3)	1 (33%)	0	1 (33%)	0	1 (33%)
Pulse oximeter (n=1)	0	0	0	0	0
Ventilator (n=7)	2 (29%	1 (14%)	2 (29%	0	3 (43%)
Miscellaneous (n=2)	0	0	0	0	0
Total Items	4 (18%)	3 (14%)	4 (18%)	0	5 (23%)

Table 5. Number and Percentage of Medical Devices Failing Electromagnetic Characteristics Tests
(Exclusive of two items failing initial inspection)

Type of Device	Radiated Emissions	Radiated Susceptibility	Conducted Emissions	Conducted Susceptibility
Infusion pump (n=1)	1 (100%)	0	1 (100%)	0
Monitor/ defibrillator (n=3)	3 (100%)	2 (67%)	2 (67%)	0
Blood pressure monitor (n=5)	4 (80%)	1 (20%)	2 (40%)	0
Suction Pump (n=3)	3 (100%)	1 (33%)	0	1 (33%)
Pulse Oximeter (n=1)	1 (100%)	0	0	0
Ventilator (n=7)	5 (71%)	1 (14%)	2 (29%)	0
Miscellaneous (n=2	2 (100%)	1(50%)	1(50%)	0
Total Items (n=22)	19(86%)	6 (27%)	8 (36%)	1 (5%)

A Portable Rigid Forced-Air Warming Cover For Pre-Hospital Transport Of Cold Patients During Rotary Wing Aircraft Search and Rescue

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1. SUMMARY

Two rigid forced-air warming covers were designed to direct heat to the torso and thighs of normothermic subjects. Subjects were heated with an AC powered heater (Bair Hugger 505, Augustine Med. Inc.) and either a commercial soft cover or the rigid covers (with the heat input at the head or abdomen). Compared to the soft cover, the rigid covers provided similar heat delivery but a higher mean skin temperature. This new heat delivery system combination may have practical value during evacuation of cold patients in rotary wing aircraft.

2. INTRODUCTION

Field care of the cold patient can be divided into two phases: 1) Rescue/non-vehicular transport; and 2) Vehicular transport. During the first phase, there are limited rewarming methods as exogenous heat can only be delivered by heat pacs, human bodies, warm water bottles or if available, inhalation of heated humidified air. The possible heat sources during vehicular transport, however, may be more numerous if the rescue/transport vehicles have a sufficient power source.

One warming therapy that has been recently developed in the last decade is forced-air warming. This method was used to warm vigorously shivering hypothermic subjects. Compared to shivering only, forced-air warming decreased the post-cooling afterdrop by 30% although the rewarming rate was unchanged [1]. In a clinical study, however, forced-air warming has been shown to almost double the rewarming rate in emergency department care of moderately-to-severely hypothermic patients who were likely not shivering [2]. A more powerful prototype of forced-air warmer has been tested on shivering subjects and demonstrated no advantage, compared to shivering, for prevention of post-cooling afterdrop but a significant increase in rewarming rate from 3.4 to $5.8°C \cdot hr^{-1}$ respectively [3].

We have recently developed a human model for severe hypothermia where inhibiting shivering with meperidine (up to 2.5 mg/kg) considerably increases core temperature afterdrop, and the core does not rewarm spontaneously for up to 3.5 hours [4]. Using this model we have shown that forced-air warming decreases the post-cooling afterdrop by 30-40% and produces a 6-fold increase in the subsequent rewarming rate [5]. Based on this data we have proposed the development of a forced-air warming system that could be used during emergency transport of cold subjects in the air (airplanes, helicopters), at sea (coast guard cutters, ships) or on land (ambulances etc.).

We felt that an appropriate system would include an existing heating unit and a new forced-air cover that would include the following criteria: rigidity to prevent collapse; storage in compact form; rapid assembly; relatively inexpensive; and should accept a heating hose from existing heating units. The goal would be for the new cover to provide at least as much heat to the skin as the existing soft blanket covers.

3. METHODS

Five healthy subjects (1 female) were instrumented according to our standard practices [4] for continuous measurements of skin temperature and heat flux (loss) at 7 sites. As well, air temperature was measured at the input site and 1 cm above each skin site to calculate heat transfer coefficients (HTC) for the total system and at the skin level respectively.

3.1 Rigid Warming Cover

The prototypes were made out of corrugated plastic (CORPLAST) and neoprene (Figure 1). The one piece units were constructed so they could collapse by folding the side and end panels over each other. When folded the units are flat for easy storage; 3 cm x 103 cm x 40 cm. The units unfold to dimensions of 30 cm x 93 cm x 62 cm to fit over the patient torso and upper legs. Neoprene collars at each end create a snug seal around the head and legs. Structural integrity of the units are maintained by fastening the end and side panels together with Velcro strips. The rigid covers have holes (5.5 cm diameter) cut in the head end and above the abdomen to provide two options for attaching the hose from the heating unit; whichever hole is not used for heat input is covered. One other similar sized hole is placed in the head end to allow continuous air flow over the skin in order to maximize convective heat transfer. Two designs were tested; cross sectionally the corners were either square or tapered.

The Bair Hugger 505 heating unit (Augustine Med. Inc.) was used with both the PORIFAC and the regular commercial warming blanket (Model 300 Full Body Blanket, Augustine Med. Inc.) to compare the heat transfer capability of these covers. In a single study, a balanced design was used to warm each

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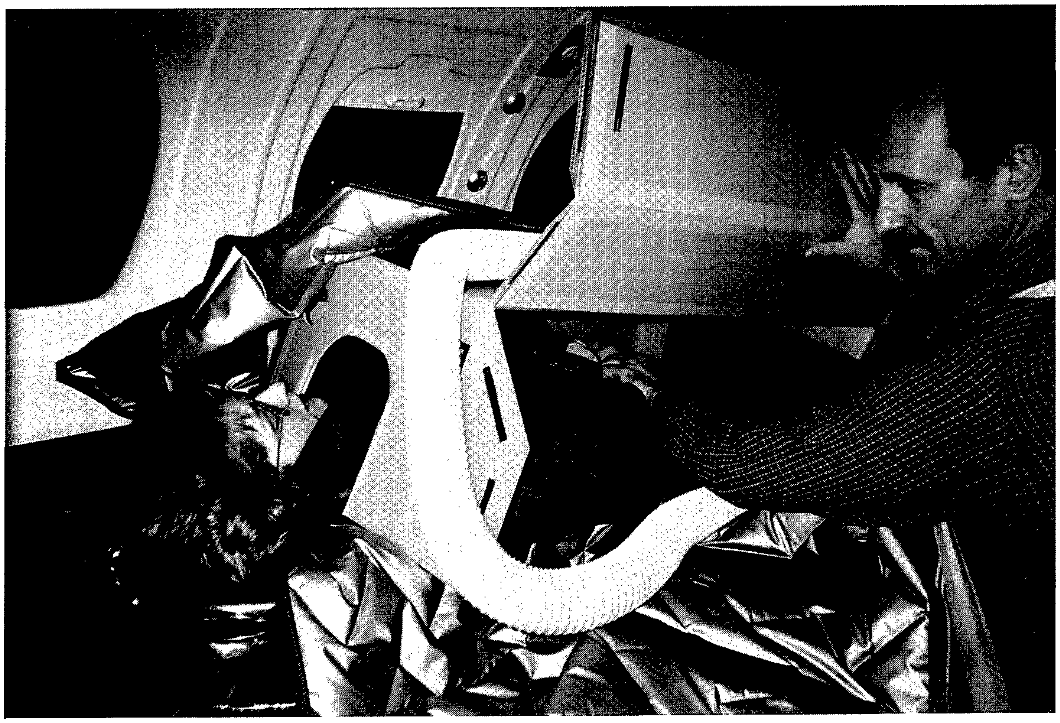

Figure 1. Rigid Warming Cover in rescue transport aircraft. The side panel can be raised to allow access to the patient. Note, patient clothing would be removed from torso.

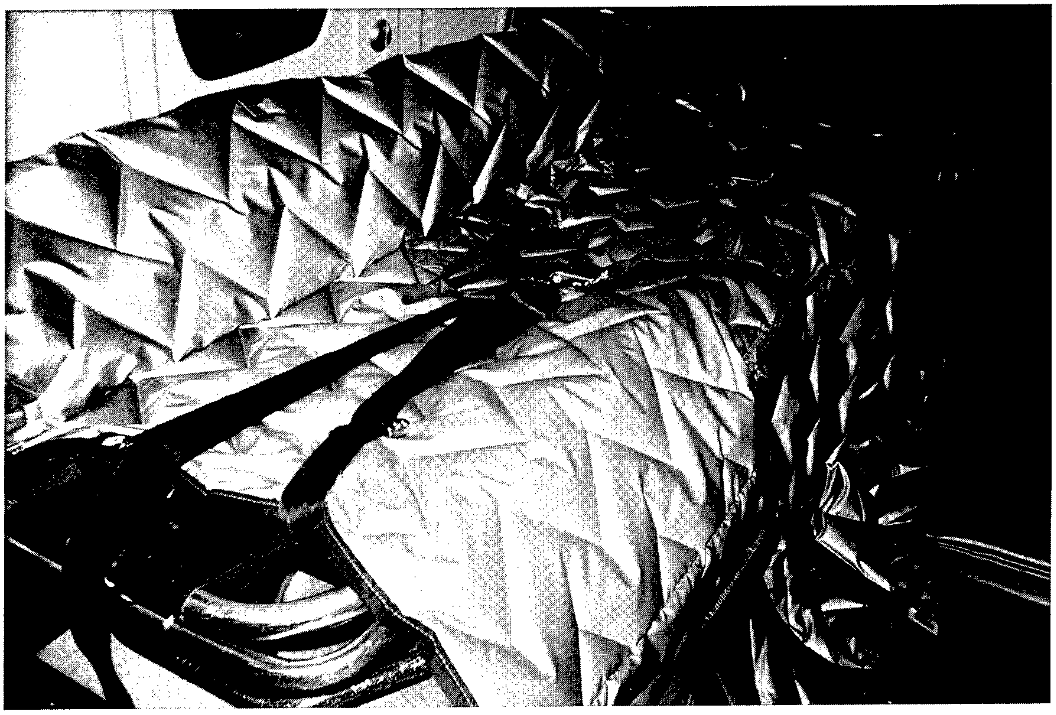

Figure 2. Altered resuce blanket with 4 velcro-secured slits for stretcher straps to pass through.

subject during five 15-minute periods with the same heater/blower used with the following "cover/heat input location" conditions: soft blanket/foot end; rigid tapered cover/abdomen; rigid tapered cover/head end; rigid square cover/abdomen; and rigid square cover/head end. Between each heating period, electric fans were used to reduce skin temperature to baseline values (~15 minutes).

Repeated measures ANOVA was used to compare group values for each condition ($\alpha=0.05$). The Fisher PLSD test was used for post-hoc analysis of significant differences.

4. RESULTS

The rigid cover, with heat input at the abdomen, provided similar heat delivery to the standard soft blanket, although the skin temperature under the cover was significantly higher in this condition (Table 1). The heat transfer coefficient, measured at the skin level, was greater with the standard soft blanket than all other configurations except the rigid square/abdomen configuration. This demonstrates the efficient, even distribution of air under this soft blanket. However, when the HTC was calculated for each total system (i.e., using input temperature), the highest values were obtained with the rigid covers with heat input at the abdomen (8.8±1.7 and 9.0±0.9 $W.m^{-2}\cdot{}^{\circ}C^{-1}$ for tapered and square respectively, compared to 6.5±1.1 $W.m^{-2}\cdot{}^{\circ}C^{-1}$ for the soft blanket). This is consistent with a greater concentration of warm air to the upper body area in this condition, and less heat loss through the top of the rigid cover than the soft standard blanket.

Table 1. Heat delivery characteristics of five "cover/heat input" configurations.

Cover/Input Location	Heat Flux (W)	T_{SKavg} (°C)	$HTC_{At\ Skin}$ ($W.m^{-2}\cdot{}^{\circ}C^{-1}$)
Blanket/ Foot	71* (11)	36.8 (0.4)	28.0*† (2.7)
Rigid Tapered/ Abdomen	67* (8)	37.5* (0.3)	23.4* (3.5)
Rigid Tapered/ Head	61 (7)	37.2 (0.4)	17.7 (1.9)
Rigid Square/ Abdomen	72* (8)	37.7* (0.3)	25.1* (4.9)
Rigid Square/ Head	60 (15)	37.1 (0.5)	18.1 (2.3)

† Significantly greater than all other conditions except tapered/abdomen ($p<0.05$).

* Significantly greater ($p<0.05$); HTC, heat transfer coefficient.

5. DISCUSSION

In order to make the new warming system compatible with aircraft transport, the standard insulated emergency transport blanket has to be altered in order to allow proper securing of the patient and stretcher within the aircraft during flight. Velcro-secured slits were placed in the blanket to allow the stretcher straps to pass through the blanket (Figure 2). The straps are passed through the slits and secured around the patient. The rigid warming cover is then placed over the patient and the blanket is wrapped around the patient and cover, thus ensuring patient security without crushing the cover.

Clinical and experimental evidence indicates that warming cold patients during transport is likely beneficial, especially if severe hypothermia inhibits the shivering response. In this condition, some type of heat may be advantageous as there may be a precipitous drop in core temperature leaving the patient in an unstable condition. The fact that the rigid cover provides as much heat transfer as the standard blanket indicates that it would be an efficient means to stabilize or increase core temperature during emergency transport. The rigid cover is not sterile and therefore would not be appropriate for perioperative use in the hospital. However, it would be acceptable for use in emergency transport of cold patients. Although both square and tapered designs provide comparable heat delivery, the tapered design is more sturdy and is therefore recommended. Finally, heat transfer would be even more efficient when in standard use because a well-insulated rescue blanket could be used to better insulate the patient and rigid cover.

Acknowledgments. NSERC Canada, and Augustine Medical Inc. for financial support, and Ms. Gillian Weseen for assistance with data analysis.

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Ergonomic and Anthropometric issues of the forward Apache crew station

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SUMMARY

This paper describes the anthropometric accommodation in the Apache crew systems. These activities are part of a comprehensive project, in a cooperative effort from the Armstrong Laboratory at Wright Patterson Air Force Base (Dayton, Ohio, USA) and TNO Human Factors Research Institute (TNO HFRI) in The Netherlands.The main objective of the project is to develop effective methods for anthropometric accommodation of crew systems, during the design process of military aircraft.

As a part of this project the Royal Netherlands Airforce asked TNO for a brief examination of the anthropometric selection criteria used for selection of Apache pilots. The criteria were verified in this examination in order to check their validity and to check if more anthropometric selection criteria were needed.

The verification process consisted of three steps. The crew station was measured using a 3D measuring device (the 'FARO arm'). The resulting data were used to compose a 3D CAD model of the crew station using Pro Engineer. The CAD model was used for the actual assessment using BMD HMS (Boeing McDonnell Douglas Human Modelling System). After the verification it was found that the anthropometric selection criteria for stature and sitting height were valid for the Apache crew station. Other selection criteria, for buttock-knee length and popliteal height, are far from valid: most candidate pilots would be rejected if the pilot were to be seated in an ergonomically acceptable posture in the Apache crew station. Additional anthropometric selection criteria for buttock-knee length, popliteal height and arm length are needed for an accurate anthropometric selection procedure.

The preliminary investigation resulted also in an efficient and fast anthropometric accommodation procedure, using the above mentioned 3D tools. This opened the possibility to test future crew stations on anthropometric aspects in an early stage of the design of new crew station. The Royal Netherlands Airforce can directly gain insight in the anthropometric qualities of these crew stations, and foresee potential anthropometric selection problems. This insight can be gained without the need for a full-scale mockup of the crew station.

1. INTRODUCTION

This report is the first result of a project concerning anthropometric accommodation in crew systems. The project is a cooperative effort of the Armstrong Laboratory at Wright Patterson Air Force Base (Dayton, Ohio, USA) and TNO Human Factors Research Institute (TNO HFRI) in The Netherlands. The objectives for this project are:

a. To provide a 3D surface geometry data base of the human body for use in the advanced design of equipment and protective gear which is compatible and interoperable among NATO populations.
b. To develop procedures, test and demonstrate the most advanced crew station accommodation methods in live subject testing, computer man-modelling and virtual or augmented reality environments, and provide recommendations for the most appropriate methods for assessing anthropometric accommodation in planned (not yet existing) crew systems.
c. To develop methods for combining the data base with the assessment methods to assure that accommodation and interoperability is achieved in the design process.

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This paper describes the results of a preliminary assessment of the forward Apache crew station. Successive reports will focus in more detail on other crew station, for instance: the T38 trainer and the F16 (Oudenhuijzen 1997).
The study aims at a minimal rejection rate of candidate pilots due to the anthropometric selection proces. It is our belief that this aim can be achieved by a proper determination of the anthropometric selection criteria. An ergonomically optimized sitting posture is a starting point for the determination of the criteria.

Crew accommodation problems still occur, despite the anthropometric selection process (it must be mentioned that the aim of crew station design activities ought to avoid the necessity for an anthropometric selection process). The currently used selection criteria are therefore being updated. This study is performed in order to check their validity and to check if more anthropometric selection criteria are needed for the Apache crew station.

Anthropometric selection criteria
Various selection criteria are used for the selection of candidate pilots. Among these are anthropometric selection criteria. The anthropometric selection criteria depend on the aircraft category for which the pilot is initially selected. The criteria used for Apache crew are shown in Table I.

Table I Anthropometric selection criteria for pilots using Apache crew station (data in mm and in inches between parentheses).

Variable	Range
Stature	1630-1930 (64.14-75.95)
Sitting Height	≤ 1020 (40.17)
Buttock-knee length	≤ 670 (26.37)

2. MODELLING OF THE CREW STATION

The method used for the crew station assessment is divided into several steps. These are:

- Measurement of the crew station;
- 3D modelling of the crew station;
- Crew station assessment using human modelling systems.The measuring and modelling activities are described in this section. The crew station assessment and the final results are described in sections 3 and 4.

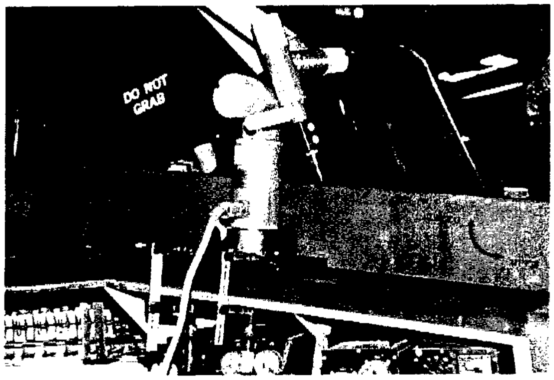


Fig. 1 The FARO arm mounted to the crew station of the Apache. The instrument measures coordinates in 6 degrees of freedom from the golden point, realtive to the cylindrical base

2.1 Measurement of the crew station

The first step taken was to measure the crew station. The measurements were carried out using a FARO arm, a digital portable coordinate measurement device. The FARO arm (see Figure 1) is a tactile measuring device and an instrumented, articulated arm with 6 degrees of freedom with an accuracy with 0.001mm. . Measurements were taken by touching a particular point, or following the contours of elements in the crew station.

The resulting 3D information (see Figure 2), a so called cloud of points, is translated to an appropriate data set for the CAD tool used at TNO HFRI.

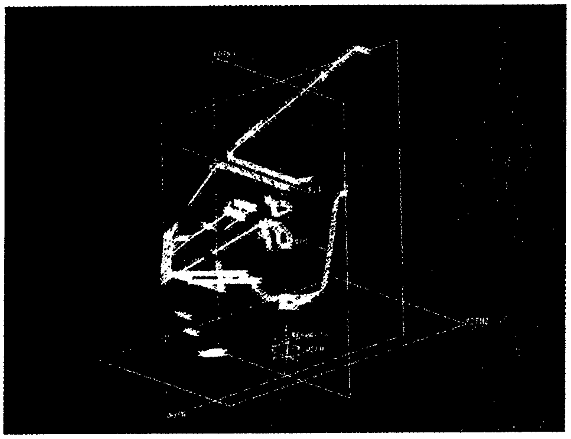


Fig. 2 The 3D geometric information of the Apache crew station: a cloud of points.

2.2 3D modelling of the crew station

The 3D cloud of points was used to compose a CAD model of the Apache crew station. The CAD tool used at TNO-HFRI for this purpose is Pro Engineer. The CAD model of the crew station can be interfaced with various other 3D tools such as Boeing McDonnell Douglas Human Modelling System (BMD HMS) and dVise (virtual environment (VE) software). The CAD model of the Apache crew station was interfaced to BMD HMS for the anthropometric assessment of the crew station.

3. CREW STATION ASSESSMENT USING HUMAN MODELLING SYSTEMS

Reverse engineering methods were used to assess both crew station, that is: the current anthropometric selection criteria were used as a starting point. The method aimed at extending the selection criteria starting from the current selection criteria. The study started with the composition of 3D human models. These human models were positioned in the CAD models of the two crew station using BMD HMS. The resulting posture was analysed, the selection criteria were verified, corrected if needed and extended when possible. The validity of BMD HMS is described by Daanen et al. (1998) and will be treated in more detail in later studies.

3.1 3D human models of the current pilot population

The anthropometric selection criteria were used to compose tall and short 3D human models, representing the given limits of the pilot population. Initially two manikins were composed for each crew station. Lower extremes for sitting height and buttock-knee length were estimated using the Multi Variate Estimator (MVE) which resides in BMD HMS. This resulted in a short and a tall pilot with the same anthropometric proportionalities. The results are shown in Table II.

Table II Anthropometric extremes according to the selection criteria. (Data in mm and in inches between parentheses; estimated data in italics.)

Variable	Dimension	
	short pilot	tall pilot
Stature	1630 (64.14)	1930 (75.95)
Sitting height	*828 (32.59)*	1020 (40.17)
Buttock-knee height	*557 (21.92)*	670 (26.37)

3.2 Sitting posture

The following aspects are essential for determination of a correct sitting posture in crew station:

Outside/inside vision

The outside/inside vision is specified from a design eye reference point (DEP). The pilot has an optimal outside and inside vision from this point. The inside vision, at the instruments, will be affected negatively if the pilots eye is positioned above the DEP. If the pilot is positioned too low, the outside vision will be limited by the glareshield. The outside vision must be in conformance with the requirements as set forth in Mil. Std. 850b. The minimal required cutoff angle/down vision for fighters is set at 25° below the horizontal sightline (azimuth).

The DEP is also a critical element due to the required pilots eye point for the Integrated Helmet and Display Sight System (IHADSS). The pilot must adjust his seat while viewing the reticle in the IHADSS Boresight Reticle Unit (BRU) in order to reach the appropriate eye height. The pilots eye is positioned in a certain virtual box in the Apache crew station by following this positioning procedure.

The crew station provides the pilots with a tactical display. This display is located in front of the pilot. The pilot has bend forward with his upper body, and lean with his forehead against a rubber pad, in order to look into this display.

Clearance

Any interference between structural elements of the crew station and the pilot should be avoided. The clearance between structural elements and the pilot must be in conformance with the requirements as set forth in Mil. Std. 1333b. The clearance between the stationary pilot (wearing gear) and structural elements of the crew station must be at least 38mm (1.5").

Intended or unintended rapid acceleration of the Apache may cause the pilot to move in the crewstation despite his or her harness. Therefore a clearance equal or more than 38mm (1.5") between the helmet and the canopy is required.

Personal equipment
Additions to anthropometric values are needed due to personal equipment of pilots. The following data (see Table III) must be taken into account during the verification process (Daanen et al., 1995). For this study the additions were limited to those caused by the helmet and shoes.

Table III Additions to anthropometric values to compensate for personal equipment (n = number of measured subjects).

Personal equipment		Apache (fighter) dimensions		
		n	Addition mm (inches)	SD mm (inches)
Helmet (vertical)		11	69 (2.72)	13 (0.51)
Shoes[1]	Height (heel)	54	38 (1.50)	7 (0.28)
	Length	106	28 (1.10)	11 (0.43)
	Width	106	9 (0.35)	5 (0.19)

Reachability
The location and actuation of controls shall be in conformance with the requirements as set forth in Mil. Std. 1333b. This standard defines the reach and grasp capability for the pilot population. "....the acquiring activity shall be considered for reach zones" (see Figure 4). Control locations shall be within these reach zones. The zones are defined as follows:
Zone 1: restraint harness locked—functional reach:

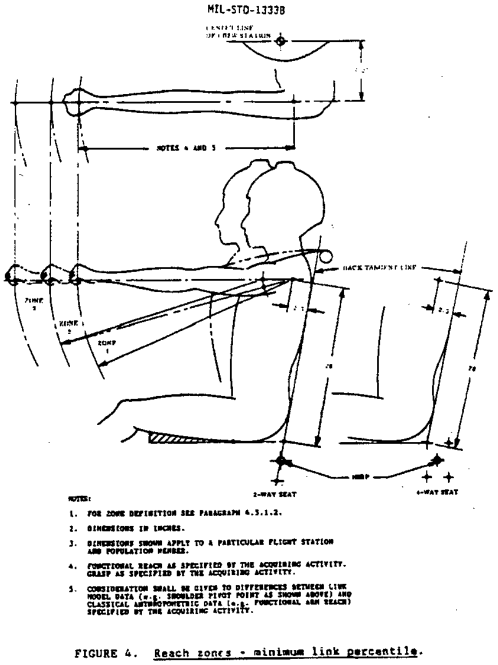
> "...controls placed within this zone shall include those frequently used during operation of the aircraft in flight phases which require full restraint. This would include such phases as takeoff, landing, low altitude high speed flight, weapons delivery and escape. This zone defines the maximum limit allowed for the placement of emergency controls and establishes the forward most operation limit of primary flight and propulsion controls. The pilot has to be positioned in the DEP during flight phases which require full restraint."

Zone 2: restraint harness locked—maximum functional reach:

> "... can be functionally reached and actuated by any crew member ... fully restrained with maximum stretch of shoulder and arm muscles. This zone defines the maximum limit allowed for the placement of helicopter primary flight controls and the placement of emergency controls other than escape controls"

Zone 3: restraint harness unlocked—maximum functional reach:

> " This zone includes the area that can be functionally reached and actuated by any crew member of the population by acquiring activity when located near the design eye position with the shoulder restraint fully extended and the arms



NOTES:

1. FOR ZONE DEFINITION SEE PARAGRAPH 4.5.1.2.
2. DIMENSIONS IN INCHES.
3. DIMENSIONS SHOWN APPLY TO A PARTICULAR FLIGHT STATION AND POPULATION MEMBER.
4. FUNCTIONAL REACH AS SPECIFIED BY THE ACQUIRING ACTIVITY. GRASP AS SPECIFIED BY THE ACQUIRING ACTIVITY.
5. CONSIDERATION SHALL BE GIVEN TO DIFFERENCES BETWEEN LINK MODEL DATA (e.g. SHOULDER PIVOT POINT AS SHOWN ABOVE) AND CLASSICAL ANTHROPOMETRIC DATA (e.g. FUNCTIONAL ARM REACH) SPECIFIED BY THE ACQUIRING ACTIVITY.

FIGURE 4. Reach zones - minimum link percentile.

Fig. 4 Reach Zones, minimum link percentiles

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[1] Daanen et. al. (1995)

stretched full length. Note that the pilot is not positioned in the DEP for reach zone 3."

Rudder/brake pedals
The pilot sitting in the most forward crew station of the Apache is the gunner. This pilot will therefore make limited use of the rudder/control pedals. His feet will rest on the floor for most of the time. However, he must be able to sit in a ergonomically acceptable manner, and has to be able to reach for the rudder control pedals.

4. CREW STATION ASSESSMENT RESULTS FOR THE APACHE

This section describes the results of the anthropometric crew assessment of the Apache crew station. Section 4.1 describes the results for the "lower" selection limits and section 4.2 for the "upper" selection limits while section 4.3 discusses the resulting additional selection criteria needed.

The anthropometric assessment starts with the composition of two manikins, using BMD HMS, which represent the currently used lower and upper anthropometric selection criteria. The next step was to find out if these manikins satisfy the boundary conditions of section 3 (optimal outside and inside view, acceptable sitting posture and able to reach for controls and displays). If not, it is sorted out if other than standard proportions would make the manikin fit and if so, the required criteria were corrected and/or additional criteria were determined and stated conformingly.

4.1 The "lower" selection criteria

Stature is of no importance for a seated workplace, such as the Apache crew station. However, stature is a clearly defined and a well understood anthropometric dimension. Almost everybody knows his or her own stature (within a certain accuracy boundary). Stature is therefore a very practical and therefore convenient selection criterion. Other selection criteria are more appropriate for a seated workplace, namely:

- Sitting height (strongly related to eye height sitting);
- Buttock-knee length;
- Popliteal height;
- Thumbtip reach.

These dimensions are essential for a seated workspace since they determine the overall envelope around the seated pilot. In fact they can be considered as critical design parameters for the crew station. One might therefore consider discarding stature as an anthropometric selection criterion for Apache pilots. This section describes how the selection criteria for sitting height, buttock-knee length, popliteal height and armreach were determined.

4.1.1 *Sitting height*

This section describes how the selection criterion for the lowest sitting height was determined. Sitting height is strongly related to the dimension for eye height sitting (r=0.97). Eye height sitting is a critical dimension due to the eye position of the gunner which is required for the IHADSS. The crew seats provide a vertical adjustability for the Apache pilots. The crew seat was adjusted in the highest possible position for determination of the smallest possible sitting height. The high seat adjustment of the seat allows short pilots to have an optimal eye position for the IHADSS and for the inside and outside view. A human model with the anthropometric characteristics of the short pilot from Table II (see section 3.1) was positioned in the CAD model of the crew station. It was found that the sitting height could be increased. The following step was to compose a new manikin

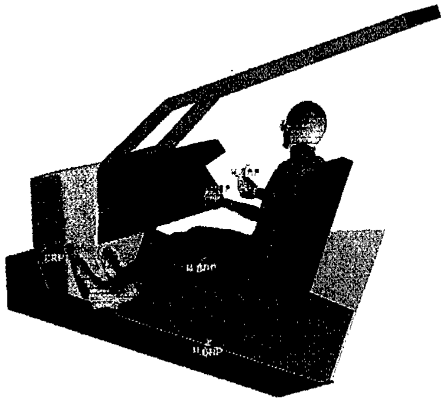

Fig. 5 The APACHE_MIN_3 human model in the Apache crew station.

with an increased sitting height, and to position this new manikin in the CAD model of the Apache crew station. This resulted in the manikin APACHE_MIN_3 with a sitting height of 853mm (33.57")(see Figure 5). The human model APACHE_MIN_3 is able to sit with his eye in an optimal position, the Design Eye reference Point (DEP). The resulting lower boundary for the selection criterion sitting height is therefore set at 853mm (33.57").

4.1.2 *Leg length*

Buttock-knee length combined with popliteal height mainly determines the total leg length. The shortest leg length is determined when a manikin rests with his feet on the rudder/brake control pedals and when the angle between the upper and lower leg does not exceed 150°. A pilot cannot apply the pedals properly when the angle of 150° is exceeded. Several manikins were composed with BMD HMS before the result was satisfying. The first manikin was APACHE_MIN_3. The buttock-knee length and the popliteal height of manikin APACHE_MIN_3 were 560 (22.04") and 395mm (15.55") respectively. The leg length of this manikin was too long for determination of the lowest possible leg length. The lower selection criteria for buttock-knee length and the popliteal height were corrected. The resulting buttock-knee length and the popliteal height (of manikin APACHE_MIN_8) are respectively 515 (20.27") and 400mm (15.74").

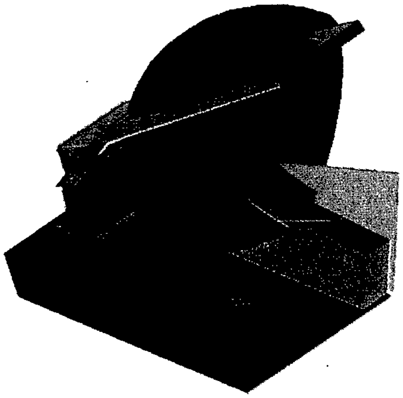

Fig. 6 The minimal reach envelope (in red) following the selection criteria

4.1.3 *Reachability (lower selection criterion)*

Mil Std. 1333b states (see section 3.2) the following: "... can be functionally reached and actuated by any crew member ... fully restrained with maximum stretch of shoulder and arm muscles. This zone defines the maximum limit allowed for the placement of helicopter primary flight controls and the placement of emergency controls other than escape controls". This means, when translated to the Apache crew station, that each pilot must be able to reach the aft half section of the side panels. The reach envelope in Figure 6 represents reach zone 2 (in red) for pilots sitting fully reclined (with the back against the backrest). The red sphere represents the reach envelope for the Apache pilots with a minimum arm length of 758mm (29.83"). This means that each selected pilot can reach for the required controls positioned within the red sphere. The resulting lower selection criterion for reach (arm length) is set at 758mm (29.83").

4.1.4 *Resulting lower anthropometric selection criteria for the Apache*

Some additional anthropometric selection criteria are needed. Table IV gives an overview of the currently used and the additional needed selection criteria for short pilots.

Table IV An overview of the currently used and the resulting lower selection criteria (values in mm; inches between parentheses)(additional needed selection criteria in italics).

Selection criteria	Currently used criteria	Proposed and adjusted criteria
	Short pilot	Short pilot
Stature	1630 (64.15)	1630 (64.15)
Sitting height	*n/a*	*853 (33.57)*
Buttock-knee length	*n/a*	*515 (20.27)*
Popliteal height	*n/a*	*400 (15.74)*
Thumbtip reach	*n/a*	*758 (29.83)*

4.2 The "upper" selection criteria

4.2.1 *Sitting Height*

The crew seat was adjusted in the lowest possible position for determination of the tallest possible sitting height. The low seat adjustment allows tall pilots to have an optimal eye position for the IHADSS and for the inside and outside view. A human model with the anthropometric characteristics of the tall pilot from Table II (see section 3.1) was positioned in the CAD model of the crew station. It was found that the maximal selection criterion for sitting height (1020mm (40.17") is valid for the Apache crew station.

4.2.2 *Leg length*

Buttock-knee length combined with popliteal height mainly determine the total leg length. The total leg length is critical for the accomodation of Dutch pilots in the Apache crew station. It was found that the selection criterion buttock-knee length had to be adjusted. Also an additional selection criterion was needed: popliteal height. The first step taken was to compose a human model with the anthropometric characteristics of the tall pilot from Table II. It was found that this manikin did not have sufficient space between the legs/knees and the Main Instrument Panel (MIP)(see Fig. 7).

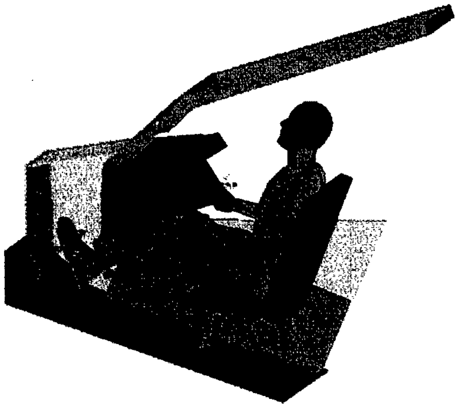

Fig. 7 Manikin APACHE_MAX_2 in the Apache crew station

A second manikin, APACHE_MAX_7, with a decreased total leg length was composed (see Table V or the most essential anthropometric data).

Table V Most essential anthropometric data for manikin APACHE_MAX_7 (values in mm; inches between parentheses).

Variable	Value
Buttock-knee length	595 (23.42)
Popliteal height	425 (16.73)

This manikin was positioned in the CAD model of the Apache crew station (see Figure 8).

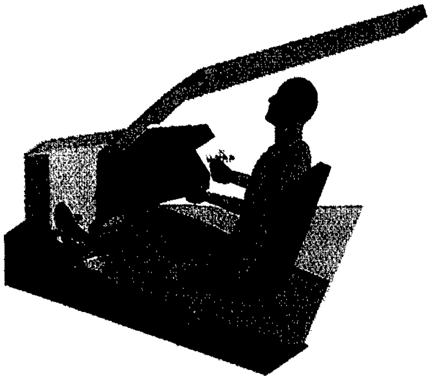

Fig. 8 Manikin APACHE_BEEN_7 in the Apache crew station

There is sufficient clearance between the legs/knees and the MIP. The resulting seated posture, however, is far from ergonomically acceptable. The seated posture is judged taking into account the duration of sorties (3hrs.) and the vibrations to which the Apache pilot is exposed. The angle between the lower back and the upper legs is too small. It is possible that pilots will suffer from (lower) back injuries if this angle is smaller than 90°. When the pilot makes use of the tactical ground display he has to bend forward and rest with the forehead against the rubber pad positioned above the tactical display.

The resulting angle will be even smaller in this case. Manikin APACHE_BEEN_7 is only sitting on his buttocks, his upper legs are not supported. The legs are not supported due to insufficient space between the seat and the pedals and due to the short sitting depth of the APACHE crew seat. The buttock-knee length and the popliteal height was decreased for the composition of the next set of manikins. Manikin APACHE_BEEN_7 has an seated posture with an angle of 90° (see Fig. 8)

The resulting upper selection criteria for buttock-knee length and the popliteal height are presented in Table VI. It is expected that the number of unaccomodated pilots will be considerable when the buttock knee length and the popliteal height from manikin APACHE_BEEN_7 will be used as selection criteria. The buttock-knee length and the popliteal height will therefore be considered as well (see also section 5) in order to lower the total number of possible unacomodated subjects.

Table VI The resulting upper selection criteria for buttock-knee length and the popliteal height. (The values for APACHE_MAX_2 will result in an ergonomically unacceptable seated posture)

Variable	Value for APACHE_BEEN_7	Value for APACHE_MAX_2
Buttock-knee length	595 (23.42)	665 (26.17)
Popliteal height	425 (16.73)	495 (19.48)

4.2.3 *Resulting maximal anthropometric selection criteria for the Apache*

The currently used maximal anthropometric selection criteria for stature and sitting height are valid for the Apache crew station. The selection criterion buttock-knee length needs to be adjusted. An additional anthropometric selection criterion for popliteal height is needed. Table VII gives an overview of the currently used and the additional needed selection criteria.

Table VII An overview of the currently used and the resulting maximal selection criteria (values in mm; inches between parentheses)(additional needed selection criteria in italics).

Selection criteria	Proposed and adjusted criteria	
	Value for APACHE_BEEN_7 (ergonomic optimal posture)	Value for APACHE_MAX_2 (ergonomic less optimized posture)
Stature	1930 (75.95)	1930 (75.95)
Sitting height	*1020 (40.17)*	*1020 (40.17)*
Buttock-knee length	*595 (23.42)*	*665 (26.17)*
Popliteal height	*425 (16.73)*	*495 (19.48)*

4.3 Recommended Anthropometric selection procedure

A significant part of the candidate pilots will not be accommodated properly in the Apache crew station and will therefore be rejected due to the proposed selection criteria. It is, however, possible that candidate pilots with anthropometric characteristics that lie beyond the proposed selection criteria will be accommodated in the Apache crew station. The reason for the possible accommodation of these pilots lies in their specific individual anthropometric characteristics. It is for instance possible that the needed addition to sitting height in order to compensate for the helmet is smaller. The individual pilots head shape may allow the helmet to be positioned lower on the head. It is therefore possible that less pilots will be rejected when the selection criterion for stature is offset for instance with 15mm (see Table VIII).

Table VIII The percentage of rejected candidate pilots for the year 2015 based on the proposed selection criteria and the effect of an offset of 15mm

	Males	Females
Proposed selection criterion for stature 1930/1630mm	16%	3%
Offset selection criterion for stature 1945/1615mm	11%	2%

It is recommended to alter the anthropometric selection procedure in order to minimize the amount of rejected pilots. The proposed procedure will consist of two parts, a pre-selection and the actual selection. The procedure takes place as follows:

The announced anthropometric selection criterion stature is set at the proposed selection criteria with in offset of 15mm. The pre-selection will result in an initial amount of candidate pilots. The actual selection takes place after the pre-selection. There are within this group of initially selected pilots those with anthropometric selection criteria that lie within the proposed range for the selection criteria, these pilots will be accommodated in an appropriate manner. There are also pilots within this group with anthropometric properties that lie beyond the proposed range. It is possible that these pilots will not be accommodated properly. These pilots will have to be tested individually making use of MDHMS in combination with a full scale accommodation trial in order to find out if they can be accommodated or not.

5. CONCLUSIONS: RESULTING SELECTION CRITERIA FOR THE APACHE CREW STATION

This study resulted in a quick review of the currently used anthropometric selection criteria. It was found that the anthropometric selection criteria for stature and sitting height were valid. The selection criterion for buttock-knee lengths needs to be corrected. Additional anthropometric selection criteria are needed for buttock-knee length, popliteal height and armlength for an accurate anthropometric selection procedure for Apache pilots. Table IX shows the resulting modified and additionally needed anthropometric selection criteria.

Tables X and XI give an overview of the expected number of rejected pilots for the Apache crew station for 1997 and 2015 respectively.

Table IX The resulting modified and additionally *(in italics)* needed anthropometric selection criteria (values in mm; inches between parentheses)

Selection criteria	Short pilot	Tall pilot, value for APACHE_BEEN_7 (ergonomic optimal posture)	Tall pilot, value for APACHE_MAX_2 (ergonomic less optimal posture)
Stature	1630 (64.15)	1930 (75.95)	1930 (75.95)
Sitting height	853 (33.57)	1020 (40.14)	1020 (40/14)
Buttock-knee length	*515 (20.27)*	670 (26.38)	*665 (26.17)*
Popliteal height	*400 (15.74)*	*425 (16.73)*	*495 (19.48)*
Thumbtip reach	*758 (29.83)*	*n/a*	*n/a*

Table X The expected percentage of rejected candidate pilots in 1997 ((fe)males #2 is ergonomically optimized, (fe)males #1 is ergonomically less optimal)

	1997			
	Females #1	Females #2	Males #1	Males #2
Lower selection criteria	25		1	
Upper selection criteria	2	65	18	98

Table XI The expected percentage of rejected candidate pilots in 2015 ((fe)males #2 is ergonomically optimized, (fe)males #1 is ergonomically less optimal)

	2015			
	Females #1	Females #2	Males #1	Males #2
Lower selection criteria	13		1	
Upper selection criteria	5	77	29	99

The number of unacommodated pilots is strongly affected by the selection criteria for buttock-knee length and popliteal height. Two numbers are given: for pilots in a ergonomic acceptable and en ergonomically unacceptable seated posture.

It can be concluded that the Apache crew station is physically not well suited for the young Dutch population since there is a considerable amount of unaccomodated candidate pilots. Especially when ergonomically acceptable sitting postures are taken into account.

The design of crew station should accommodate the current and future Dutch male and female pilots, in order to prevent a high number of rejected candidate pilots. It is therefore necessary to investigate the possibility to make improvements to the Apache crew station, and especially for the adjustment range for the rudder/brake control pedals.

A new anthropometric selection procedure is recommended. This procedure aims at a minimal number of rejected pilots and a maximal number of properly accommodated pilots. The proposed selection procedure consists of two steps.

During the first step, a pre-selection, pilots with a stature ranging from 1615mm and 1945mm are selected. The resulting group candidate pilots are then divided into two groups during the second step:

1. Those candidate pilots with a stature between 1630mm and 1930mm, these pilots will be measured and tested according to the proposed selection criteria. The pilots that pass the selection can be accommodated in the APACHE crew station;
2. Those candidate pilots with a stature beyond 1630mm and 1930mm, these pilots will be tested individually using MDHMS and a fullscale test. These individual test must point out if these pilots can be accommodated in the APACHE crew station.

The preliminary investigation resulted in an efficient and fast anthropometric accommodation procedure, using the above mentioned 3D tools. This enables testing of future crew station on anthropometric aspects in an early stage of a project such as the development of crew station. The Royal Netherlands Airforce can directly gain insight in the anthropometric qualities of these crew station, and foresee potential anthropometric selection problems. This insight can be gained without the need for a full-scale mockup of the crew station.

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SIMULATOR VERSUS IN-FLIGHT MEASUREMENT OF PILOT PERFORMANCE

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SUMMARY

A quasi-experimental approach assessed the comparability of simulator versus in-flight results. Flight data from three sleep-deprivation studies were pooled. Twenty aviators were included, 10 who flew a UH-60 helicopter simulator and 10 who flew a UH-60A aircraft under the influence of Dexedrine® or placebo during 40 hours of continuous wakefulness. Performance on straight and levels, right and left turns, climbs and descents, and a left-descending turn (assessed at 0100, 0500, 0900, 1300, and 1700) tended to correspond in the simulator and aircraft. Generally, performance under Dexedrine was better than under placebo. However, only half of the maneuvers showed consistent, statistically significant stimulant/fatigue effects in both flight platforms. Measurement sensitivity was lower in the aircraft, likely because of error variance due to environmental influences (weather, temperature, and turbulence) and other factors (radio traffic and anxieties about safety). Thus, actual in-flight studies, while desirable in terms of face-validity, underestimate the impact of stressors such as fatigue on pilots.

INTRODUCTION

Accurate measurement of pilot performance has been of interest to the aviation community for years.[1] The implementation of new operational procedures, fielding of various pharmacological interventions, understanding of stressor effects, and improvement of training and tactical operations all rely upon sensitive and reliable methods of evaluating aviator performance. Due to technological advances, it is now possible to examine piloting skill via computerized flight scoring systems both in simulators and aircraft. However, while some studies have been conducted under actual flight conditions,[2,3,4,5] the majority have relied on simulators.[6,7,8,9]

Simulator studies are attractive because of low relative cost, greater accessibility, optimal experimental control, and improved safety relative to in-flight investigations. Simulations have contributed much toward the understanding of aviation-related problems and the effects of stressors or interventions. One category of pilot-performance study that has benefited from flight simulation is the area of drug research. Studies on several compounds have been published over the past 10 years, and each has yielded valuable information for the operational environment. For example, studies on the chemical defense compound, atropine sulfate, have characterized the drug's effects and eased concerns about the fielding of this medication. Dellinger, Taylor, and Porges[7] and Simmons et al.[8] showed that an atropine injection did not preclude an aviator's safe return to base despite the presence of performance decrements with large doses. Other studies have shown that: the antihistamine terfenadine is safe for aviators because it does not degrade performance;[9] the hypnotic triazolam, while effective, is of limited use in pilots because of its potential side effects;[10] and the stimulant dextroamphetamine is efficacious for maintaining aviator performance during sleep loss.[11,12]

These findings presumably apply to the aircraft environment; but there is limited empirical evidence on this point. Typically, the option of conducting in-flight studies has been abandoned in favor of working in a simulator because of feasibility and safety factors. Simulations possess a high degree of face validity, and convenience factors make them a highly attractive alternative to the aircraft. However, since few investigators have the time or resources necessary to perform simulator versus in-flight comparability studies, it is unclear how well findings from one situation will actually generalize to the other.

The few comparability studies which do exist suggest that simulations are more sensitive than aircraft studies to performance changes. Caldwell and Jones[13] compared helicopter in-flight data[4] to helicopter simulator data[8] collected as part of the atropine work mentioned above. They concluded the simulator offered the most sensitivity to drug effects, especially when a small or "moderately impairing" dose was used. Billings et al.[2] reported similar findings (simulator more sensitive than aircraft) in their work with secobarbitol, particularly when low doses of the drug (100 mg) were tested. They concluded simulators were useful for sensitive, inexpensive investigations of stressors and pilot performance; however, they advised caution when extrapolating from the simulator to the aircraft because of the differences in pilot arousal levels from one situation to the other.

How much of a difference really exists between the results of laboratory simulations and actual in-flight investigations, and is this difference a genuine cause for concern? Based on the limited number of available comparison studies, it is difficult to answer these questions. On the one hand, it is possible that the only good reasons for conducting simulations are cost and safety related, and that all other things being equal, an in-flight

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investigation is the most desirable alternative. On the other hand, perhaps the increased sensitivity in the simulator environment provides information that is totally obscured in the more realistic, but more variable, in-flight domain.

The present paper attempts to address these issues by comparing simulator and aircraft data collected during three studies on the effects of dextroamphetamine in sleep-deprived pilots. The first was a study by Caldwell et al.[11] in which six male aviators were kept awake for 40 continuous hours while they flew a helicopter simulator and completed other evaluations. During the last half of one period, the subjects were administered 10-mg doses of Dexedrine (at 0000, 0400, and 0800), and during the final hours of the other period, the subjects were given placebo. Dexedrine improved composite measures of flight performance on four out of six sets of maneuvers, with the most notable benefits occurring at 0500 and 0900 when the fatigue was most severe. These results were confirmed by Caldwell et al.[12] in a systematic replication of the 1995 study . In this case, six females were used as subjects. Once again, the simulator flight data showed the majority of maneuvers were better after Dexedrine than placebo, and often, there were drug by time-of-day effects. It was concluded that Dexedrine was a viable fatigue countermeasure for sleep-deprived pilots. However, since both tests were conducted in a simulator, an in-flight study was felt to be necessary before definitive conclusions were possible. Thus, in 1997, a systematic replication was performed in a specially-instrumented UH-60 helicopter.[5] Results again indicated improved performance with Dexedrine on many maneuvers; however, the impact of the drug was not as robust as in the earlier simulator investigations. In fact, many of the drug-by-time effects (seen in the simulator) were less pronounced or absent in the aircraft, and composite scores proved inadequate to detect many of the in-flight drug effects (root mean square errors of control parameters were used instead).

Both these simulator and in-flight investigations offered evidence of the efficacy of dextroamphetamine, but there were differences. To examine the extent of these differences, the present investigation was performed.

METHODS

Subjects

Two groups of subjects were compared. Ten UH-60 pilots (mean age of 28.3 years) were selected from among the 12 pilots who contributed data in the simulator studies. The final group consisted of 5 males and 5 females who were combined to create the "simulator group." All 10 UH-60 pilots (mean age of 31.9 years) who contributed to the in-flight study were used in the "in-flight group." These were all males. Female volunteers were screened for pregnancy prior to admission. The average amount of flight experience for the participants in the simulator study was 1,003 hours (ranging from 140-3,400 hours) and the average flight experience for the participants in the in-flight study was 1,278 hours (ranging from 540-3,100 hours). The approximate average weights for participants in the two groups averaged 150 and 155 pounds, respectively.

Apparatus

Drug dosing. At each dose, subjects received two orange capsules (placebo or Dexedrine®) with 8 ounces of orange juice. Placebo capsules were filled with lactose, and each of the Dexedrine® capsules contained one, 5-mg Dexedrine® tablet.

UH-60 flight simulator. Simulator flights were conducted in a UH-60 simulator with a 6-degree-of-freedom motion base and a full-visual cockpit in which the visual display was set for daytime flight. Flight data (heading, airspeed, altitude, etc.) were acquired by computer and converted to composite flight scores using specialized routines.[14]

UH-60 helicopter. In-flight evaluations were conducted in a specially-instrumented Sikorsky JUH-60A helicopter. Both day and night flights were conducted under unaided conditions (night vision goggles were not used at night). Flight data were recorded with a locally-manufactured, computerized flight monitoring system, and were converted to composite flight scores using the Jones and Higdon[14] software routines mentioned above.

Procedure

Each subject completed several flights under Dexedrine® and placebo. The dose-administration schedule was fully counterbalanced and double blind.

Flight evaluations. Flight performance evaluations required subjects to perform a variety of instrument flight maneuvers arranged in a standardized upper-airwork profile. These maneuvers required reliance on aircraft/simulator flight instruments rather than external visual cues. In the simulator, subjects began by performing hovers and low-level navigation tasks followed by instrument maneuvers and a formation flight, but only the instrument maneuvers are examined here. In the aircraft, subjects began by flying the aircraft to a safe maneuvering area prior to performing the same instrument maneuvers which were used in the simulator flight (after the hovers and navigation). The last descent was deleted from the aircraft flight profile for safety reasons.

Maneuvers were flown in the same order each time (see Table 1). The first group of these was flown with the automatic flight control system (AFCS) trim engaged (the normal mode when flying the UH-60), and the second group was flown with the AFCS trim turned off. The AFCS trim system enhances the stability of the aircraft/simulator, and when the AFCS is turned off (to simulate a system failure), accurate flight control becomes much more difficult, increasing the pilot's workload.

Table 1. Flight profile

Manueuver	AFCS On/Off
Straight and level no. 1	On
Left standard-rate turn no. 1	On
Straight and level no. 2	On
Climb no. 1	On
Right standard-rate turn no. 1	On
Straight and level no. 3	On
Right standard-rate turn no. 2	On
Climb no. 2	On
Descent no. 1	Off
Left descending turn	Off
Left standard-rate turn	Off
Straight and level no. 4	Off
Right standard-rate turn no. 3	Off
Descent no. 2	Off

During each maneuver, the subject was required to maintain control over specific flight parameters (i.e., heading, altitude, etc.) which varied across maneuvers. For instance, heading control was evaluated during straight-and-level flight, but not turns. Scores which reflected how well the subject flew each maneuver were calculated in two steps. First, the control scores for the parameters relevant to each maneuver were determined using the limits presented in Table 2. Thus, if a subject never deviated from the assigned heading by more than 1 degree, a score of 100 resulted, whereas larger deviations produced lower scores. Second, the scores from each parameter were averaged into a single composite score. Thus, if a subject scored 100 on heading, 85 on altitude, and 90 on airspeed, a composite score of 91.7 would have resulted. Composite scores were not collapsed across all of the maneuvers in each flight because of the differences in the parameters which made up the scores in each.

Table 2. Scoring bands for flight performance data

	Maximum deviations for scores of:					
Measure (units)	100	80	60	40	20	0
Heading (degrees)	1.0	2.0	4.0	8.0	16.0	> 16.0
Altitude (feet)	8.8	17.5	35.0	70.0	140.0	>140.0
Airspeed (knots)	1.3	2.5	5.0	10.0	20.0	> 20.0
Slip (ball widths)	0.0	0.1	0.2	0.4	0.8	> 0.8
Roll (degrees)	0.8	1.5	3.0	6.0	12.0	> 12.0
Vert. Speed (feet/m)	10.0	20.0	40.0	80.0	160.0	>160.0
Turn Rate (degrees/s)	0.3	0.5	1.0	2.0	4.0	> 4.0

<u>Testing schedule</u>. Subjects arrived at the laboratory at 1800 on Sunday when the study was explained, informed consent was obtained, and a medical evaluation was conducted. Subjects with past psychiatric or cardiac disorder, a history of sleep disturbances, or any current significant illness would have been rejected, but none of these problems were found. On Monday morning, the aviator completed three training flights (at 0900, 1300, and 1700) before retiring at 2300 hours. On Tuesday, there were three control-day flights (at 0900, 1300, and 1700), but at the end of the day, sleep was not permitted. On Wednesday at 0000 the first drug/placebo dose was administered, followed by subsequent doses at 0400 and 0800. Flights occurred at 0100, 0500, 0900, 1300, and 1700. On Thursday, after 8 hours of recovery sleep, the subject repeated the same schedule as was used on Tuesday. On Friday, testing continued with drug/placebo doses at 0000, 0400, and 0800, and flights were conducted at the same times as those on Wednesday. The participant retired at 2300 on Friday and was released after awakening at 0700 on Saturday morning.

RESULTS

Analysis of variance (ANOVA) was used to analyze scores for each maneuver. The between-subjects factor was group (simulator, aircraft) and the within-subjects factors were drug (placebo, Dexedrine) and session (0100, 0500, 0900, 1300, 1700). For maneuvers flown more than once during the profile, a third factor, iteration (i.e., turn 1 and turn 2), was added. Significant interactions and main effects were followed by analysis of simple effects and/or pairwise contrasts. Huynh-Feldt adjusted degrees of freedom were used in the event of violations of the compound symmetry assumption. Only the effects involving group or drug are discussed below.

Straight and Levels

The ANOVA for the four iterations of straight and levels (SLs 1-4) indicated a drug-by-iteration-by-group interaction (F(3, 54)=5.09, p=.0036) due to a drug-by-iteration effect in the simulator but not the aircraft. In the simulator, performance under placebo was lower than under Dexedrine during both SL2 and SL4, while at SL1 and SL3 there was no drug-related difference (see table 3).

Table 3. Means for SL iterations under placebo and Dexedrine

Group	Drug	SL1	SL2	SL3	SL4
Simulator	Pbo	89.7	84.4	82.6	74.6
Simulator	Dex	91.7	87.7	85.7	84.3
Aircraft	Pbo	73.0	68.0	66.5	71.1
Aircraft	Dex	74.5	71.1	69.0	73.7

There was an iteration-by-group interaction (F(2.78, 50.02)=16.31, p<.0001). In both groups, higher scores occurred during SL1 than in SL2 or SL3, but only in the simulator was there a further drop at SL4. In the aircraft, scores during this last SL were slightly higher than scores at SL2 and SL3. A drug-by-iteration interaction (F(3, 54)=6.57, p=.0007) was due to differences across the SLs under placebo versus Dexedrine. There was no drug effect in SL1, but Dexedrine produced moderately better performance than placebo in SL2 and SL3, and much better performance in SL4.

There were main effects on group (F(1,18)=53.70, p<.0001)and drug (F(1,18)=16.17, p=.0008). Scores were higher in the simulator than in the aircraft (85.08 versus 70.86) and higher under Dexedrine than placebo (79.71 versus 76.23).

Left Standard-Rate Turns

The ANOVA for the left standard-rate turns (LSRT1, LSRT2) indicated a drug-by-iteration-by-group interaction for scores (F(1,18)=5.12, p=.0363) which analysis of simple effects indicated was due to a drug-by-iteration effect in the simulator, but not in the aircraft. In the simulator, performance under placebo was worse than performance under Dexedrine at LSRT2 while there was no difference at LSRT1 (see table 4).

Table 4. Means for LSRTs under placebo and Dexedrine

Group	Drug	LSRT1	LSRT2
Simulator	Pbo	78.6	59.1
Simulator	Dex	80.2	66.7
Aircraft	Pbo	62.2	60.5
Aircraft	Dex	63.6	62.3

There was a session-by-group interaction (F(4, 72)=2.45, p=.0540) due to differences across the testing times in the aircraft but not in the simulator. In the aircraft, there were higher scores at 0100 than at 0500 or 1300, and higher scores at 0900 than at 1300. In addition, there was a slight recovery in performance from 1300 to 1700 (the means for each flight from 0100-1700 in the aircraft were 63.9, 62.0, 62.4, 59.6, and 62.8, respectively). There was an iteration-by-group interaction (F(1,18)=50.97, p<.0001) due to better performance during LSRT1 than during LSRT2 in the simulator, but not in the aircraft. There was a drug-by-session interaction (F(3.57,64.27)=3.64, p=.0125) due to differences among testing times under placebo but not Dexedrine. Scores under placebo dropped from 0100 to 0500, 0900, and 1300, after which there was a recovery from 0900 to 1700 (see Figure 1). There was a drug-by-iteration interaction (F(1,18)=7.06, p=.0161) due to a significant drug effect in the second, but not the first LSRT (higher scores under Dexedrine than placebo in LSRT2).

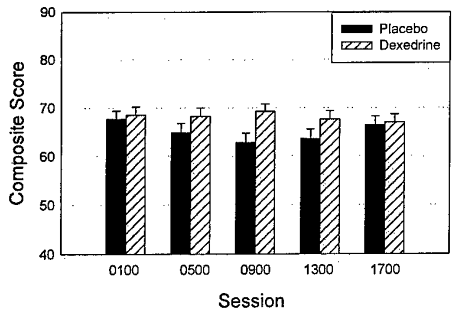

Figure 1. Effect of drug and session on LSRT scores.

There was a main effect on group (F(1,18)=10.76, p=.0042) because of better overall performance in the simulator than the aircraft (71.16 versus 62.13), and there was a main effect on drug (F(1,18)=10.64, p=.0043) due to higher comp scores under Dexedrine than placebo (68.18 versus 65.12).

Climbs

The ANOVA for the two climbs (Climb1, Climb2) indicated a drug-by-session-by-iteration interaction (F(3.38,60.85)=2.69, p=.0480) which analysis of simple effects indicated was due to a drug-by-session interaction at Climb2, but not Climb1. Analysis showed that although there were session differences both under placebo and Dexedrine (p<.01), the pattern was different. Under placebo, performance was better at 0100 than at 0900 or 1300, and performance was better at 0500 than at 0900. Under Dexedrine, there were no differences among the first three sessions, but performance at both 0500 and 0900 was better than performance at 1300, and performance at 0900 also was better than at 1700 (see Figure 2).

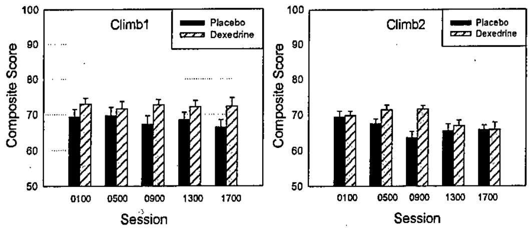

Figure 2. Effects of drug and sessions on the climbs.

There was a session-by-group interaction (F(3.65,65.73)=3.88, p=.0086) due to differences across the testing times in the aircraft, but not in the simulator. In the aircraft, performance was better at 0100, 0500, and 0900 than at 1300, and performance was better at 0100 than at 1700 (see table 5).

Table 5. Means for climbs in simulator versus aircraft flights

Group	0100	0500	0900	1300	1700
Simulator	72.9	71.9	70.5	73.4	71.5
Aircraft	67.8	68.2	67.1	63.1	63.7

An iteration-by-group interaction (F(1,18)=13.07, p=.0020) occurred due to higher scores during Climb1 than Climb2 in the simulator, but not the aircraft. A group main effect (F(1,18)=3.11, p=.0020) was found due to higher scores in the simulator than the aircraft (72.05 versus 65.98), and a drug main effect (F(1,18)=14.18, p=.0014) occurred because of better performance under Dexedrine than placebo (70.73 versus 67.30).

Right Standard-Rate Turns

The ANOVA for the three right standard-rate turns (RSRT1, RSRT2, RSRT3) indicated there was no 3-way interaction.

However, there was a drug-by-group interaction (F(1,18)=8.84, p=.0082) due to better performance under Dexedrine than placebo in the simulator, but not in the aircraft. There also was an iteration-by-group interaction (F(2,36)=14.76, p<.0001) which was again because of an effect only in the simulator. In the simulator, scores in RSRT2 were better than those in the other two iterations and RSRT1 was better than RSRT3 (see table 6).

Table 6. Means for RSRT iterations in simulator versus aircraft

Group	RSRT1	RSRT2	RSRT3
Simulator	74.4	78.1	69.8
Aircraft	60.2	60.7	60.2

There was a drug-by-iteration interaction (F(2,36)=3.51, p=.0404) because of differences in the drug effects across iterations. Dexedrine was associated with better performance than placebo in all three RSRTs; however, the difference was larger in RSRT3 than in RSRT1 and RSRT2.

In addition to these interactions, there was a group effect (F(1,18)=23.30, p=.0001) attributable to better performance in the simulator than in the aircraft (74.10 versus 60.39); and a drug effect (F(1,18)=19.88, p=.0003) due to higher scores under Dexedrine than placebo (69.17 versus 65.32).

Descents

The ANOVA for the two iterations of descents indicated a drug-by-group interaction (F(1,18)=7.74, p=.0123). Although there were Dexedrine-related improvements in both the simulator and the aircraft, it was most pronounced in the simulator. A drug-by-session interaction (F(4,72)=3.79, p=.0074) was due to differences across the testing times under placebo but not Dexedrine. Scores under placebo dropped substantially from the 0100 flight in comparison to the remaining flights. In addition, scores at 0500 were higher than those at 0900 (see Figure 3).

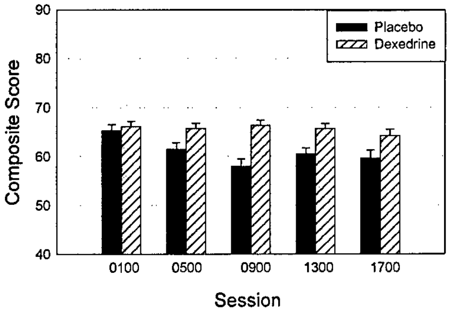

Figure 3. Effects of drug and session on the descents.

Lastly in the descents, there was a drug main effect (F(1,18)=35.84, p<.0001) due to higher scores under Dexedrine than placebo. The means were 65.66 versus 61.03.

Left Descending Turn

The ANOVA for the left descending turn showed a drug-by-group interaction (F(1,18)=5.38, p=.0323) due to higher scores under Dexedrine than placebo in the simulator, but not in the aircraft. Also, there was a drug main effect (F(1,18)=13.45, p=.0018) because of better performance under Dexedrine than placebo (55.44 versus 51.61). There were no overall differences on the grouping factor (simulator versus aircraft).

DISCUSSION

Both the simulator and aircraft data reported here were collected with virtually identical protocols which involved the same drug doses, test schedules, and experimental procedures. The overall findings from both indicated Dexedrine was associated with better performance than placebo in sleep deprived pilots. Statistically significant drug main effects occurred on every maneuver--a finding consistent with previous reports which have shown Dexedrine effectively attenuates the performance declines associated with sleep loss.[5,11,12] However, interpretation of some of the drug effects was complicated by the presence of interactions suggesting differences between the simulator and in-flight testing.

Differences between drug-related effects in the simulator versus the aircraft were seen in four of the six maneuvers. In three cases, drug effects were found in the simulator which did not attain statistical significance in the aircraft, and in one case, the observed drug effects were more pronounced in the simulator than in the aircraft (although differences did occur in both). These findings suggest a higher degree of measurement sensitivity in the simulator environment which, in some situations, could lead to research conclusions that may not generalize in a straightforward manner to the actual flight environment. This finding supports Billings et al.[2] and Caldwell and Jones[13] who concluded drug effects were more consistent and orderly in simulator than in aircraft tests.

There are a number of possible reasons for differences in the two situations, but the first and most probable is that weather turbulence, which creates large, frequent, and random flight-path deviations, is omnipresent in the aircraft and totally absent in the simulator. This has the net effect of reducing the accuracy of in-flight performance by causing the pilot to constantly correct for deviations which are unpredictably induced by wind gusts or thermal air currents. That this was an issue in the present study was evidenced by the presence of group main effects in half of the maneuvers. Wind turbulence accentuates statistical error variance to the point where only the most robust drug (or other) effects are large enough to outweigh random sources of performance variability. Thus, while there were consistent tendencies for performance to have been better under Dexedrine than placebo throughout all of the data, the differences sometimes were not large enough (in relationship to other sources of variance) to attain statistical significance.

The second explanation is that arousal levels in the actual flight environment may have been substantially higher than those in the simulator. This arousal difference may have increased performance capacity under the placebo condition to the point where some of the effects of sleep deprivation may have been overcome by anxiety alone. Thus, although Dexedrine improved alertness both in the simulator and the aircraft, the improvement relative to the no-drug condition tended to be smaller under actual flight conditions.

Other possible explanations for the differences between simulator and in-flight results include: environmental changes (in constrast to the simulator study, it was impossible to maintain a constant temperature and illumination level from one test period to another in the aircraft); differences in instructor pilots (flight-hour or crew-rest restrictions forced the use of different safety pilots in the aircraft but not in the simulator); and timing fluctuations (the simulator sessions always began precisely on time, whereas air traffic considerations sometimes introduced delays under actual flight conditions). Also, the results may have been influenced by the fact that there were differences in the pilot experience levels between the two groups. Subjects in the in-flight group had almost 300 hours more flight time than those in the simulator group. Thus, in-flight participants may have been better equipped to deal with the effects of fatigue under the placebo condition, and this may have minimized the apparent benefits from Dexedrine. Any of these factors could have decreased the sensitivity of the in-flight study.

Of course it is no suprise that a tightly controlled laboratory experiment would have yielded results different to those obtained in the real world, but it is interesting to note the extent to which these differences might have clouded the conclusions from at least one of our investigations. Based on the in-flight results alone, the efficacy of Dexedrine for sustaining flight performance during sleep loss would have been underestimated, and this would have been inconsistent with the robust improvements observed in the appearance, behavior, mood, and physiological arousal levels of the research subjects. It is interesting to note that in both the in-flight and simulator investigations, staff members, safety pilots, and the volunteers easily differentiated between the Dexedrine and placebo conditions before the blinding procedure was removed. The fact that these robust effects did not manifest themselves more substantially in actual in-flight performance is unfortunate; however, because of the simulator investigations, we were able to attribute this difference to methodology rather than the intervention itself. In this case, the simulator made clear the beneficial effects of an interevention that otherwise might have been overlooked. If the drug under consideration had been one that impaired rather than improved performance, a similar problem would have arisen (lack of sensitivity in the aircraft), but the consequences could have been more problematic since it might have been concluded that this hypothetical drug was safe for flight operations when in fact the opposite was true. Because of this, it is recommended that testing be conducted first in the laboratory to gain a thorough understanding of the effects of any stressor or countermeasure on aviator performance, before conducting in-flight evaluations to "prove the concept" in the real world.

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THE EFFECTS OF EXERCISE VERSUS NAPPING ON ALERTNESS AND MOOD IN SLEEP-DEPRIVED AVIATORS

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SUMMARY

A quasi-experimental approach assessed the comparability of exercise versus napping for maintaining alertness in aviators deprived of sleep. Subjective and objective data from two sleep-deprivation studies were pooled. Thirty aviators were included, 18 who were given zolpidem induced naps during the deprivation period and 12 who exercised during 40 hours of continuous wakefulness. Performance on Repeated Tests of Sustained Wakefulness, Profile of Mood State questionnaires, and Visual Analogue Scales was assessed. Zolpidem-induced naps were superior to rest in sustaining mood, and alertness on both a subjective and objective test. Napping was also clearly better than exercise for attenuating changes in mood and subjective alertness typically produced by sleep loss.

INTRODUCTION

Tasks that place heavy demands on working memory, that call for sustained attention, or require creativity even for short durations are affected by sleep deprivation.[1] In general, tasks that require sustained concentration and vigilance such as monitoring radar screens and control panels are the most susceptible to the influences of sleep deprivation (SD). Sleep deprivation produces periods of slow performance and periods of non-performance or lapses. As the duration of sleep loss increases, the lapses increase in frequency and duration. Williams et al.[2] found that on a 10 minute monotonous vigilance test which is typically performed without difficulty, after one night of sleep loss, performance began to degrade within 7 minutes. On this same task, after 2 nights without sleep, the degradation began after 2 minutes. Hockey[3,4] has shown that sleep deprivation produces slower reaction times on tracking tasks and that subjects become more easily distracted and have difficulty concentrating on sustained attention tasks such as card sorting.

There is considerable evidence which shows that napping can be used as an effective countermeasure to the effects of sleep deprivation. In a study conducted by Bonnet,[5] some subjects napped before a 52-hour continuous performance period while others remained awake. The nap was beneficial in keeping performance and alertness from decreasing for up to 24 hours of sleep loss as compared to the no-nap condition. In a study by Naitoh and colleagues,[6] subjects were given a 3-hour nap after being awake for approximately 24 hours. After the nap, they were required to stay awake an additional 20 hours. Results indicated that this 3-hour nap reduced the decline in performance during the additional work period. Other studies have found similar results using 24 hours of sleep deprivation.[7-10] In each case, naps taken prior to extended periods of sleep loss, "prophylactic naps," considerably attenuated the decrease in performance.

Naps are especially effective when they are properly planned in relation to the timing of work requirements, and placed at times that are most conducive to natural sleep.[11-19] A nap is most beneficial if taken before significant sleep loss occurs, a prophylactic nap,[7,8] and sleep occurs most readily and performance is sustained most effectively when naps are placed in the circadian troughs (although post-nap grogginess may be exacerbated at that time).[8,21] Unfortunately, in real world scenarios, it is often difficult to place naps at times when optimal results will be achieved. For instance, while personnel may have opportunities for prophylatic naps prior to sustained wakefulness, operational constraints may prevent the scheduling of naps when people are most able to initiate and maintain sleep. In these situations, it may be necessary to use a short acting hypnotic such as zolpidem tartrate to promote restful and restorative sleep.

Low doses of zolpidem (10 mg or less), have been shown to effectively promote sleep without inducing long-term hangover effects, alterations in sleep architecture, or severe performance impairments.[22-26] Additionally, it has been shown to improve the benefits of prophylatic napping during periods of significant sleep loss. Caldwell and Caldwell[27] reported that while both placebo and zolpidem-induced naps were beneficial in terms of sustaining mood, alertness, and performance throughout the final 24 hours of 38-hour periods of sustained operations, zolpidem maximized these effects. Subjects were able to go to sleep faster, maintain sleep longer, and sleep more soundly following zolpidem administration when compared to placebo-induced naps. While postnap grogginess was seen for about 3 hours after awakening, it was present following both placebo and zolpidem administration. The benefits from napping, which

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were seen toward the middle and end of the deprivation period, however, appeared to outweigh the early postnap inertia.

Despite these promising results, hypnotics such as zolpidem can produce adverse central and peripheral nervous system reactions such as headache, drowsiness, dizziness, lethargy, and a drugged feeling. The most common gastrointestinal reactions are nausea, dyspepsia, and diarrhea.[28,29] For these reasons, some aviators may be unable or unwilling to use hypnotics during periods of sustained operations despite sleep loss. Even if personnel are willing to take advantage of this medication, the opportunity to expose each individual to a test dose to check for possible idiosyncratic reactions prior to deployment may not exist. Thus, it is important to find non-pharmacological interventions which can be used in cases where hypnotics are contraindicated.

Studies which examine arousers such as noise on SD performance, typically find that decrements in performance are to some degree ameliorated. Wilkinson[30] has reported that 100db of white noise reduced the error rate produced by 32 hours of SD on a serial reaction task. Similarly, 75db of pink noise improved speed of response at 0500, the lowest point of the circadian dip, on a spatial memory test in subjects subjected to partial sleep deprivation.[31]

While exercise is considered an arousing activity, little is known about the effects of exercise on alertness in SD subjects. To date, most sleep deprivation studies have employed exercise as an additional stressor.[32-35] The most commonly used schedules of exercise are bouts of 30 continuous minutes/hour or 1 continuous hour/3 hours, throughout the duration of sleep deprivation. Despite the strenuous exercise schedules used in the above mentioned studies, cognitive and physiological performance decrements in sleep deprived subjects were not compounded by exercise. In the case of Englund et al.[34] vigilance decrements may have been delayed by as much as 8 hours when compared to nonexercising controls.

In spite of the extreme levels and durations of exercise typically used, there are some hints throughout the literature that exercise may be used in a practical manner, outside of the laboratory, as an effective method to increase alertness/arousal during periods of sleep deprivation. It has been shown that short bouts of submaximal exercise can improve cognitive performance in nonsleep deprived subjects.[36,37] Davey[37] examined the function of various amounts of exercise on a continuous attention task. Exercise had an inverted U-shaped effect on performance. Low intensity exercise had little or no effect, moderate submaximal exercise enhanced performance and exhaustive exercise produced decrements in performance. These and other studies provide supporting evidence that moderate levels of exercise can affect cognitive performance by raising arousal levels. While evidence does exist for the arousing properties of acute submaximal exercise, few studies have been done which examine exercise induced arousal on cognitive performance in sleep deprived subjects.

The only study to date which directly examined the arousing effects of short bouts of submaximal exercise in sleep deprived/restricted subjects was conducted by Horne & Foster.[38] These researchers examined the effects of 10 minutes of exercise, at four different levels 0%, 20%, 40%, and 70%VO_2max, on performance of sleep restricted people. Subjects were restricted to 4 hours of sleep on the previous night and subsequently tested between 14:00-16:00. These authors used the Wilkinson Auditory Vigilance Test (purported to be extremely sensitive to changes in sleepiness/alertness). The 30-minute test was given prior to exercise and re-administered following 10 minutes of exercise and 5 minutes of rest. Exercise at all levels (20, 40, & 70%) produced some improvement in vigilance. The only significant change, however, was seen in subjects who exercised at the highest level (70%). Postexercise vigilance measures were significantly better in the high exercise group. Self-rated alertness was improved in all exercise groups but the effects were short lived, lasting only 10-15 min in the low (20%) and middle conditions (40%). In the high exercise condition (70%), this effect was extended to 30 minutes. As self-rated measures of sleepiness and exertion are more highly correlated with performance than physiological measures,[32,35,39] it may be possible to capitalize on the alerting effects of short bouts of submaximal exercise in sleep deprived aviators.

In cases where subjects are required to perform sustained attention tasks such as monitoring radios and radar screens or routine tasks such as preflighting aircraft, short bouts of submaximal exercise may prove to be a useful cognitive arouser. The literature shows that exercise produces improvements or can reduce or delay the onset of decrements in auditory and visual vigilance tasks in sleep deprived subjects.[34,36,37] However, of these studies, none have been aviation-related. When operational or medical constraints prevent the use of pharmacological countermeasures (hypnotic-induced naps) for the alleviation of aircrew fatigue, behavioral strategies such as short bouts of exercise may provide a safe alternative for maintaining aviator performance.

This paper attempts to address these issues by comparing data collected during two studies, one on the effects of zolpidem-induced naps, and the second on the effects of exercise for maintaining alertness in sleep-deprived pilots. The first was a study by Caldwell et al.,[40] in which 18 aviators were kept awake for 12 hours, given a 2 hour nap or 2 hours of rest, followed by an additional 24 hours of wakefulness. During the period of sustained wakefulness, subjects completed mood, cognitive, and alertness evaluations. The second was a study by LeDuc et al.,[41] in which 12 aviators were kept awake for 40 continuous hours. Subjects were awake for 18 hours prior to the beginning of the intervention. Subjects exercised (treadmill running at 70% VO_2max) or rested for 10 minutes, every 2 hours, during the next 18 hours of sustained wakefulness. During this period, subjects completed cognitive, mood, and alertness evaluations. Data from the two studies were combined for the present set of analyses.

METHODS

Subjects

Two groups of subjects were compared. Thirty subjects between the ages of 22 and 35 (mean=26.6) were recruited from Fort Rucker and other Army installations. Twenty-nine subjects were males and one was female. Fifteen of the subjects were flight students, and 15 were rated helicopter pilots. All subjects gave informed consent and were medically evaluated prior to testing. Subjects were healthy, used only small amounts of caffeine (no more than three 8-ounce cups caffeinated coffee or five 12-ounce caffeinated soft drinks per day) and reported no problems sleeping. Subjects remained inside of the U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama, for the duration of testing. Groups consisted of 18 volunteers who participated in a zolpidem-induced napping study and 12 volunteers who participated in a study examining the effects of exercise on alertness in sleep deprived aviators.

Apparatus

Mood evaluation. The Profile of Mood States (POMS) was used to assess subjective reports of mood at various times throughout the day.[42] This paper-and-pencil questionnaire consisted of 65 items which measured affect on 6 scales: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. The answers were scored by hand with scoring templates.

Sleepiness evaluations. Subjective sleepiness was measured via the Visual Analog Scale (VAS) which consisted of eight 100 mm lines centered over the adjectives "alert/able to concentrate," "anxious," "energetic," "feel confident," "irritable," "jittery/nervous," "sleepy," and "talkative". At the extremes of each line, "not at all" and "extremely" were printed, respectively.[43] Scores consisted of the distance of the subject's mark from the left end of the line (in mm).

Objective sleepiness/alertness was measured using the Repeated Test of Sustained Wakefulness (RTSW) in which the subject's electroencephalogram (EEG) was recorded for up to 20 minutes using a Nihon Kohden electroencephalograph (Model No. EEG-4321P) during the test to objectively determine whether or not he/she successfully remained awake (subjects were awakened and removed from the room immediately if they fell asleep). Records were scored in terms of the number of minutes from lights out until sleep onset, up to 20 minutes.[44]

Procedure

Both groups of subjects completed assessments of flight performance, cognitive performance, mood, and sleepiness during the 40-hour periods of sleep deprivation. Flight performance and cognitive performance were assessed at different times (more than 2 hours apart) during these studies and thus were deemed not comparable. However, mood and sleepiness evaluations from the two studies were given within +/- 20 minutes of each other.

Mood evaluation. For the zolpidem group, the POMS was administered every 2 hours beginning at 0900 on training and control days and at 0100 on sleep deprivation days. The last administration occurred at 1900 each day. For the exercise group, the POMS was administered every 2 hours beginning at 0920 on training and control days and at 0120 on sleep deprivation days. The last administration occurred at 1920 each day. The test was administered using the standard POMS answer sheet on which subjects indicated how well each of 65 adjectives described the way they were feeling at the time. The test took approximately 5 minutes.

Sleepiness evaluations. For the zolpidem group, the VAS was administered every 2 hours from 0905 to 1905 on training and control days, and from 0105 to 1905 on test days. For the exercise group, the VAS was administered every 2 hours beginning at 0925 on training and control days and at 0125 on sleep deprivation days. The last administration occurred at 1925 each day. Each subject was given a test sheet containing a series of 100 mm lines drawn horizontally over the adjectives described earlier. At the extremes of each line, "not at all" and "extremely" were printed, respectively. The subject placed a mark on the line to indicate his present feelings.

The RTSW occurred every 4 hours, immediately following the VAS. Subjects were required to lie on a bed in a quiet, darkened room after being instructed as follows: "lie as still as possible with your eyes closed and do your best to remain awake." During the RTSW, EEG data were recorded from electrode sites C3, C4, O1, and O2, referenced to the contralateral mastoid. The subject was allowed to remain in bed either until 20 minutes had elapsed or until he/she entered stage 2 sleep (the first K complex or sleep spindle). The elapsed time from lights out until sleep onset was recorded.

Testing schedule. Subjects arrived at the laboratory at 1800 on Day 1 when the studies were explained, informed consent was obtained, and a medical evaluation was conducted. Subjects with past psychiatric or cardiac disorder, a history of sleep disturbances, or any current significant illness would have been rejected, but none of these problems were found. Following wake up on Day 2, the aviators completed three practice sessions on all tests before retiring. In the zolpiden study on Days 3, 5, and 7 tests were conducted to establish baseline. At the end of Days 3, 5, and 7, subjects in the zolpidem study were given a 2 hour zolpidem-induced nap, a placebo-induced nap, or 2 hours of rest, in a counter balanced order, from 2100-2300. They remained awake until 2205 on the following evenings (Days 4, 6, and 8). On Days 3 and 5, in the exercise study tests were conducted to establish baseline. At the end of Days 3 and 5, subjects in the exercise study remained awake. This group exercised (treadmill running at 70% VO_2max) or rested for 10 minutes every 2 hours beginning at 0100 and ending at 1900 on Days 4 and 6. Conditions were also counter balanced. The first test during the deprivation conditions began at 0100 in the Zolpidem group and 0120 in the exercise group. Testing continued until the participants retired at 2300.

RESULTS

Data were transformed to Change from Baseline using the formula Test score-Baseline score=Change score. The last baseline score prior to the deprivation period was used in the transformations. BMDP4V was used to conduct a series of analyses of variance (ANOVA) on mood and sleepiness.[45] The between-subjects factor was group (Zolpidem, Exercise, and Rest). The Rest group was not a true level of a between subjects factor as it was composed of data from the rest conditions of two studies and not an independent sample. However, in order to compare the effects of two interventions to performance under no intervention, rest data from all 30 subjects were pooled and treated as a third group. The within-subjects factor was session (10 levels for POMS and VAS and 6 levels for RTSW). Significant interactions and main effects were followed up by analysis of simple effects and/or pairwise contrasts. Huynh-Feldt adjusted degrees of freedom were used when violations of the compound symmetry assumptions were observed.

Mood evaluation

Change scores from each of the six scales on the POMS were analyzed with a two-way ANOVA. There were three levels of the between subjects factor group (Zolpidem, Exercise, and Rest) and 10 levels of the within subjects factor session (0100, 0300, 0500, 0700, 0900, 1100, 1300, 1500, 1700, and 1900). No main effects or interaction were observed on the depression-dejection or anger-hostility scales.

Tension-anxiety. The analysis indicated that there was a significant group by time interaction on self-reported tension-anxiety (F(18,504)=1.63, p<.05). Simple effects tests showed that changes in tension-anxiety scores across sessions were significant only in the Zolpidem and Rest groups (figure 1). Contrasts indicated that a sharp and significant increase in tension-anxiety was evidenced in the Zolpidem group at 1100. While ratings did decrease at the 1300 session, they remained higher than those reported during the first session at 0100. In the Rest group, tension-anxiety scores rose significantly between 0100 and 0300, and between 500 and 0700. With the exception of the 1500 session, ratings remained elevated above the 0100 through 0300 levels. Differences between groups were seen only at the 0300 and 0700 times, with the Exercise group reporting significantly more tension-anxiety than the Zolpidem group.

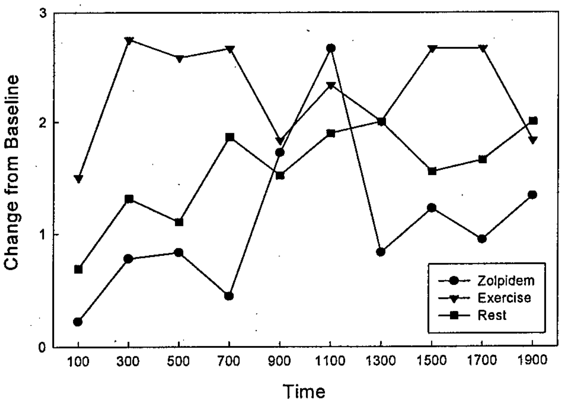

Figure 1. Effects of group and time on POMS tension-anxiety change scores.

Regardless of group assignment, ratings changed significantly across sessions during the deprivation period (F(9,504)=2.85, p<.003). An increase in tension-anxiety occurred during the deprivation period from 0100 to 0300. Tension-anxiety scores remained elevated throughout testing. A further increase in tension-anxiety was seen at 1100, but this elevation was not maintained (figure 2).

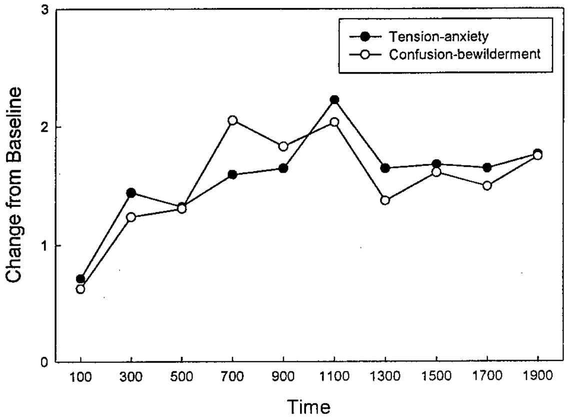

Figure 2. Effects of time on POMS tension-anxiety and confusion-bewilderment change scores.

Confusion-bewilderment. The analysis indicated that there were main effects for group (F(2,56)=3.77, p<.03) and time (F(9,504)=5.73, p<.001) but no group by time interaction. As illustrated in figure 2, confusion-bewilderment scores steadily increased from 0100, reaching a high at the 0700 session. Ratings remained elevated throughout the 1100 session and were followed by a decline at 1300. This level was then maintained throughout the rest of the deprivation period. Despite the decrease at 1300, ratings never returned to the levels seen during the first session at 0100. The main effect for group was attributable to the overall lower rating of confusion-bewilderment in the Zolpidem group than seen in either the Exercise or Rest groups (figure 3).

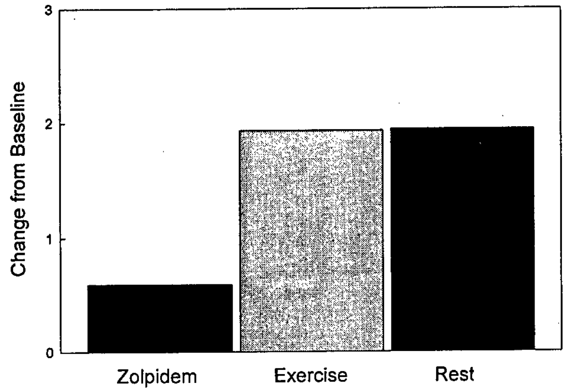

Figure 3. Effect of group on POMS confusion-bewilderment change scores.

Vigor-activity. The analysis indicated that group assignment had no impact on vigor-activity scores (no group main effect or group by time interaction). A main effect for time was seen (F(9,504)=12.12, p<.001). As illustrated in figure 4, vigor-activity scores steadily and significantly declined from the 0100 to 0700 session. Ratings then plateaued throughout the remainder of the deprivation period, with the exception of a slight increase at 1300. This increase was not enough to return vigor-activity scores to the level initially seen during the first deprivation test at 0100.

Fatigue-inertia. As shown in figure 4, changes in fatigue-inertia were mirror opposites of those seen in vigor-activity. A sharp and significant increase in fatigue-inertia occurred during the deprivation period from 0100 to 0700. Scores then remained elevated throughout testing, with the exception of a slight decrease at 1300. As with vigor-activity, this change was not enough to return fatigue-inertia scores to the level initially seen during the first deprivation test at 0100.

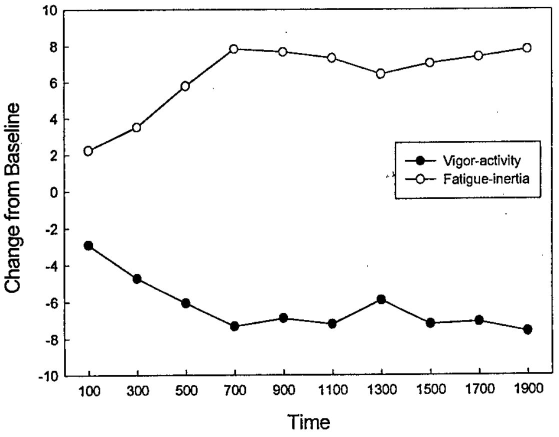

Figure 4. Effects of time on POMS vigor-activity and fatigue-inertia change scores.

Sleepiness evaluations.

Change scores from each of the eight scales on the VAS were analyzed with a two-way ANOVA. There were three levels of the between subjects factor group (Zolpidem, Exercise, and Rest) and 10 levels of the within subjects factor session (0100, 0300, 0500, 0700, 0900, 1100, 1300, 1500, 1700, and 1900). No main effects or interaction were observed on the anxiousness or jitteriness scales.

VAS alertness. The two-way ANOVA revealed a main effect for group, (F(2,56)=4.72, p<.02), a main effect for time (F(9,504)=8.86, p<.001), and a group by time interaction (F(18,504)=2.36, p<.002). As illustrated in figure 5, while self-rated alertness decreased to 9.58 below baseline after the zolpidem nap, alertness decreased twice as much in the Exercise (23.3) and Rest (22.67) groups.

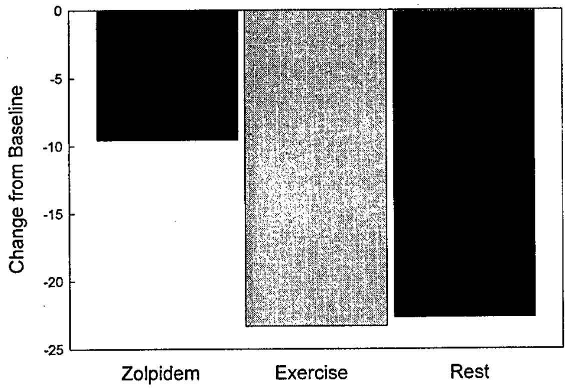

Figure 5. Effect of group on VAS alertness change scores.

Examination of the group by time interaction found that alertness ratings in the Zolpidem group did not change significantly across sessions. This differed from the Exercise and Rest groups. These groups exhibited very similar patterns of change across sessions (figure 6). Alertness declined steadily from the 100 to 0700 session. Some recovery was evident between 0900 and 1300; however, following the 1300 session, alertness began a slight decline which was maintained throughout the remainder of the deprivation period. Further, both the Exercise and Rest groups reported significantly lower levels of alertness than the Zolpidem group at 0500, 0700, 1500, 1700, and 1900.

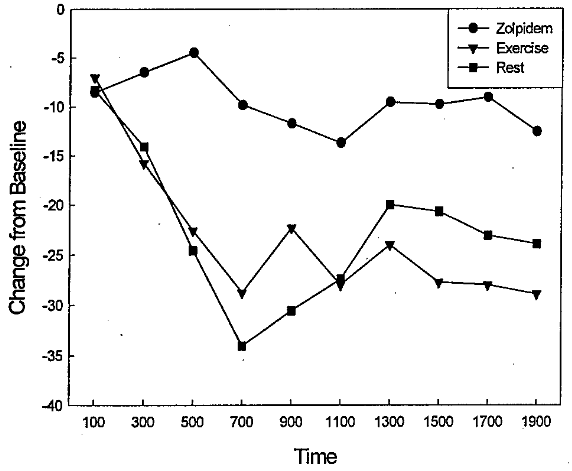

Figure 6. Effects of group and time on VAS alertness change scores.

Contrasts on the main effect for time showed that alertness decreased steadily from 0100 to 0700. Ratings then plateaued throughout the 1100 session. A slight increase in alertness was evident at 1300, followed by a decline at 1500 and 1700. The increase at 1300 was not enough to return alertness scores to levels initially seen during the first deprivation test at 0100.

VAS energy. A main effect for group (F(2,56)=3.50, p<.04) and a main effect for time (F(9,504)=7.63, P<.001) were found. There was no significant interaction of group by time. Contrasts showed that energy ratings in the Rest group were significantly lower than those in the Zolpidem group (figure 7). While ratings in the Exercise group tended to be lower than Zolpidem, they were not statistically different.

Contrasts on the main effect for time showed that energy exhibited a similar pattern of change across sessions as was seen in alertness scores. Energy decreased steadily from 0100 to 0700. Ratings then plateaued throughout the 1100 session. A slight increase in alertness was evident at 1300. This increase, however, was not enough to return alertness scores to the level initially seen during the first deprivation test at 0100.

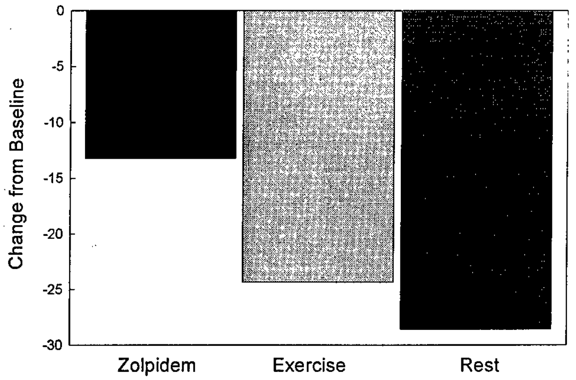

Figure 7. Effect of group on VAS energy change scores.

VAS confidence. Group assignment had no effect on confidence scores. No main effect for group or interaction with group was observed. There was a main effect for time (F(9,504)=2.70, p<.005). The changes in confidence scores across sessions were very similar to those seen in energy and alertness scores. Confidence scores decreased from 0100 to 0700. Ratings then plateaued throughout the 1100 session. Slight increases in confidence scores were seen at 1300 and 1900, however, ratings remained well below those of the first session at 0100.

VAS talkativeness. No main effect for group or interaction with group was observed. There was a main effect for time (F(9,504)=3.24, p<.001). As with other VAS measures, talkativeness declined from 0100 to 0700. Scores on this measure then began to increase such that the scores at 1300 and 1500 were not different than the one observed at 0100. A sharp decline in talkativeness was evident during the last two test sessions at 1700 and 1900.

VAS irritability. No main effect for group or interaction with group was observed. There was a main effect for time (F(9,504)=4.33, p<.001). Irritability slowly increased from 0100 to 0700 and plateaued through 1100. Irritablity then declined at 1300 to the level seen during the first test session at 0100 and remained at this level throughout the 1900 session.

VAS sleepiness. The two-way ANOVA showed that there was no main effect for group, however, a group by time interaction (F(18,504)=1.97, p<.01) and time main effect (F(9,504)=12.58, p<.001) were seen. The main effect for time was due to the sharp and significant increase in sleepiness reported from the 0100 to 0700 session. Sleepiness then remained significantly elevated throughout the deprivation period. Analysis on the interaction of group and time found that the sleepiness ratings did not change significantly across session in the Zolpidem group (figure 8). In the Rest group, sleepiness ratings increased sharply from 0100, reaching a high at 0700. Ratings then declined through the 1300 session but remained above those from the 0100 and 0300 sessions. Ratings began to climb during the last few sessions but never reached the highest level seen at 0700. In the Exercise group, sleepiness ratings increased sharply from 0100 to 0500. While slightly higher ratings were seen at 0700 and 0900, they were not significantly different from the 0500 session. A decline in sleepiness was seen at 1100. Sleepiness then steadily increased from 1300 to 1700, with scores reaching their highest at 1700. A slight decline was seen during the last session. Additionally, scores at 0500, 0700, and 0900 were significantly higher in the Rest group than the Zolpidem group.

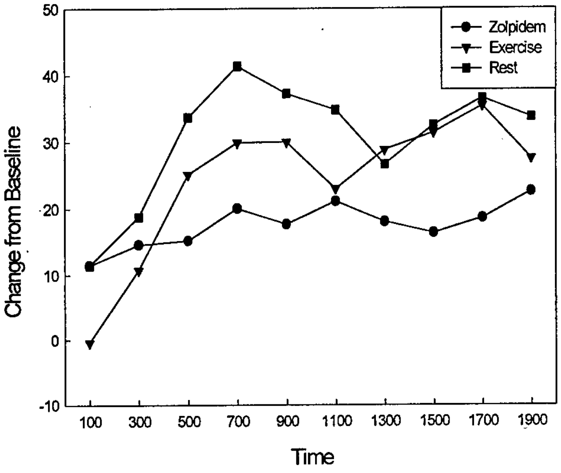

Figure 8. Effects of group and time on VAS sleepiness change scores.

RTSW. Change scores from the RTSW were analyzed with a two-way ANOVA. There were three levels of the between subjects factor group (Zolpidem, Exercise, and Rest) and 6 levels of the within subjects factor session (0110, 0510, 0910, 1310, 1710, and 2110). The ANOVA showed that there was a main effect for group (F(2,56)=15.09, p<.001) and a main effect for time (F(3.78,211.71)=27.95, p<.001). The main effect for group (figure 9) was due to the large decrease (in time to sleep onset) from baseline observed in the Rest group (-13.58 minutes). This decrease was significantly more than that exhibited by either the Zolpidem (-7.96 minutes) or Exercise group (-8.00 minutes). While the Zolpidem and Exercise groups did exhibit a decrease from baseline on minutes to stage 2 sleep, the decrease in both groups was nearly identical.

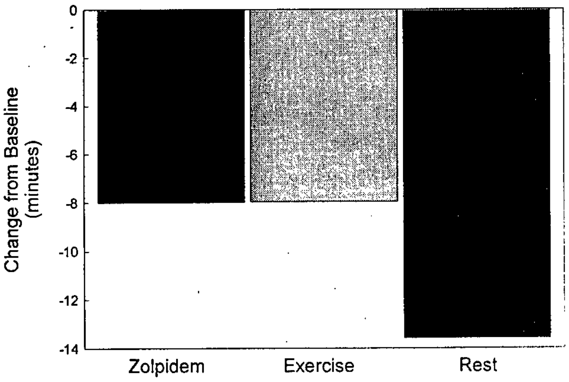

Figure 9. Effect of group on RTSW change scores.

Contrasts on the main effect for time showed that onset of stage 2 sleep decreased significantly from 0110 to 0910 (figure 10). This decreased level was maintained throughout the 1710 test. Some recovery was seen during the last session at 2110 (approximately 3 minutes).

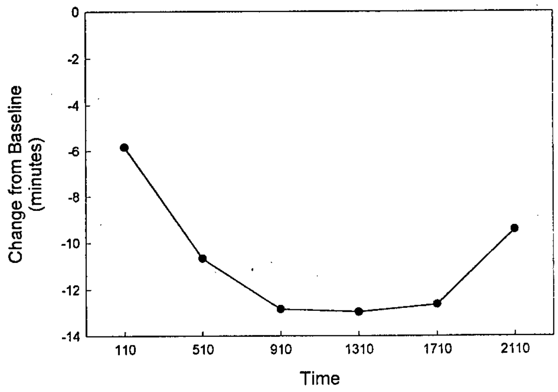

Figure 10. Effect of time on RTSW change scores.

DISCUSSION

In terms of the effectiveness, POMS data revealed a zolpidem-induced nap was clearly better than exercise or rest at attenuating the increase in confusion and bewilderment typically seen during long periods of sleep loss. Smaller increases in tension and anxiety ratings were also seen at several time points during the deprivation period in the Zolpidem group. The VAS results indicated that subjects in the Zolpidem group experienced smaller decrements in alertness and energy than subjects in the Exercise or Rest groups. Additionally, sleepiness ratings were lower at 0500, 0700, and 0900 in the Zolpidem group than in the Rest group (times when it is particularly difficult to remain alert). Thus, it is clear that zolpidem-induced naps were superior to rest alone in terms of sustaining subjective feelings of alertness during sleep deprivation. These findings are consistent with those of Bonnet,[5] who found that self-reports of vigor were improved by a 200-minute nap in comparison to a no-nap condition. It was also evident that in many instances a nap produced better effects on mood and subjective alertness when compared to 10 minute bouts of exercise.

The results from the Repeated Tests of Sustained Wakefulness indicated that both zolpidem naps and exercise significantly increased the subject's ability to remain awake, when compared to rest, during a 40-hour period of continuous wakefulness under conditions designed to make this very difficult (lying down in a dark, quiet room). While subjects were able to remain awake much longer following a nap or when exercising throughout the deprivation period, they still entered stage 2 sleep approximately 8 minutes faster than when they were not sleep deprived. Scores obtained from the RTSW, an objective measure of sleepiness/alertness did not totally match the self-reported sleepiness/alertness scores from the VAS, a subjective measure of sleepiness. Subjects in the Exercise group reported being significantly less alert than the Zolpidem napping group, yet the RTSWs were virtually equivalent (-8.00 and -7.96, respectively). A similar trend was observed when examining the energy scale from the VAS. This lack of agreement between subjective and objective measures of sleepiness/alertness is not surprising in light of previously reported low correlations between the two types of measures.[46-48]

The results of the RTSW suggest that, despite decreases in subjective measures of alertness, exercise produces alerting physiological effects equivalent to those produced by a zolpidem-induced nap. These results should, however, be tempered. The RTSWs used in this comparison were conducted 20 minutes following exercise. Results from the awake EEGs conducted 50 minutes following exercise showed that the subjects were less alert than if they had not exercised.[41] Conversely, in the zolpidem study, central nervous system activation was significantly improved by napping.[40] Thus, our overall conclusion is that a zolpidem-induced nap is superior to exercise in terms of attenuating mood and alertness decrements typically associated with sleep deprivation.

ACKNOWLEDGMENTS

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Helmet Mounted Displays for the 21st Century: Technology, Aeromedical & Human Factors Issues

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1. INTRODUCTION

The introduction of Helmet Mounted Sights and Displays into operational aircraft, and the increased mass of the helmets due to the incorporation of the additional image source, optical trains, the combiners/projection system as well as the wiring, optical supports etc, and the subsequent changes in centre-of-gravity have all conspired to push the biomechanical safety aspects in the wrong direction. Most current work is in minimising the mass of these components and lowering the CofG of the head mounted mass by a number of clever design fixes, and this is producing some reductions in helmet or head-mounted mass. The average current flight helmets weigh in the region of 1.5kg (3.3lb), whilst the lightest is in the region of 1.1kg (2.5lb). In some cases these lower masses results in a reduction of impact protection and, whilst in some cases, this may be acceptable for operational reasons, reduction in impact safety margins is not generally or widely acceptable. To complete the head mounted weight, the mass of an oxygen mask, at some 300g (0.66lb), must be added. Helmets incorporating displays are of course heavier and the current average mass, excluding oxygen mask, is in the region of 1.9kg (4.2lb) and 2.2kg (4.8lb) with O_2 mask Fig 1 gives an indication of the static loads on the head, counterbalanced by the posterior neck muscles.

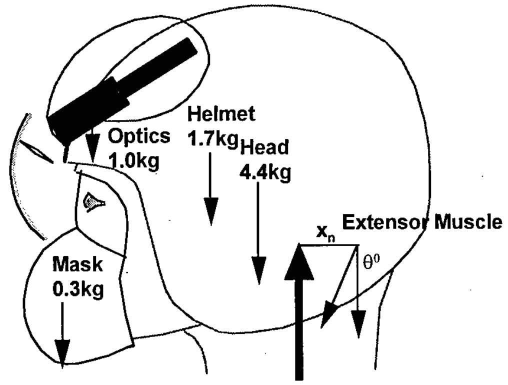

Fig 1: Head/neck loading biomechanics

With helmet mounted displays, compensation for the increase in mass due to the display components is often made by a trimming of the helmet structure and a subsequent loss of helmet impact safety levels. If the use of this modification (i.e. helmet 'trimming') route is not an optimum way to engineer lightness into a helmet display, a fundamental rethink of the helmet design concept maybe, and this is the approach taken by DERA Farnborough in one of their long term research programmes (Ref 1). The aim was to review new lightweight, stable designs, with improved centres of gravity and moments of inertia, which would improve pilot performance and reduce the risk of neck and spine injury in fast jets during highly agile manoeuvres and ejection. For helicopters the mass reduction is intended to improve the protection in the crash case by reducing the inertia of the HMD and to improve the impact protection for multiple impacts.

The approach was to investigate the mechanics of new materials for the head/helmet interface, integral lightweight shell structures and an assessment of the human characteristics of integrated design functions.

2. MECHANICAL & STRUCTURAL ISSUES

Materials for a stiff, two part clam-shell helmet, of sandwich construction, together with multi-layer high impact attenuating liners were modelled, constructed and tested, and have produced data to design closer fitting helmets shells. Alternative methods of producing form fit liners were used and evaluated and highly conformal stable liners produced. Head aggregation modelling techniques, using data from laser scanning of heads, were analysed to develop size rolls for future designs.

2.1 Form Fit Liners

In the design for the mechanics of materials for the head/helmet interface, maximal head coverage and conformality were considered high priority. Following initial materials surveys three approaches were studied to produce head liners; live head mouldings, liners moulded from replica heads and liners machined from laser scanned head data. The first method was abandoned early due to thermal and toxicity effects, the second proved to be an effective approach but was superseded by the use of laser scanning techniques and CAD/CAM manufacture of the form fit liners. This methodology was more attractive and a cheaper approach in the longer term with the benefit of high stability and the optical alignment being completed in the computer following head laser scanning. Due to the personalised nature of the form fit liners, the optical systems can be set for the helmet, eliminating heavy adjustment mechanisms.

2.2 Shell Construction

In the process of determining the helmet design, basic integral lightweight shell structures and impact attenuating liners were constructed and impact tested, both physically and with a Finite Element model initially as representative

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hemi-spheroid test shapes. Gradual evolution in shape led to a helmet shaped construction that formed the basis of the lightweight helmet shell.

The impact tests, to the UK standard for helmet test, BS 6658, demonstrated excellent impact attenuating properties.

The manufacturing development and Impact Assessment was carried out by the Structural Materials Centre at DERA Farnborough and a 'cardinal point' specification (i.e. the maximum of technical freedom) given as to the technical direction needed. Double Diaphragm Forming techniques were used to successfully produce the fibre reinforced skins, carbon fibre inners and glass fibre outer, and significant development made in the press-forming of high performance cellular materials for use a energy absorbing liners. A sandwich construction helmet shell had reduced mass compared to conventional single skin GRP or ABS helmets, but maintained the high stiffness necessary to eliminate the mechanical decoupling of optical systems used in more flexible helmets. Until the final designs, it is difficult to provide comparative masses, as it is possible to design the helmet either for maximum impact attenuation or minimum mass for acceptable impact limits. The aim, however, is to produce a helmet mass of initially 1.6kg (3.52lb) which includes optics and oxygen mask - i.e. a basic helmet mass of 1 to 1.2kg - with high levels of impact protection This, with a better understanding of the materials technology, should allow this 1.6kg mass to be reduced in time to around 1.4kg. As a result of enhanced stiffness, and the utilisation of high performance materials, the shell demonstrated impact performance and energy management greatly superior to current conventional helmet shell designs.

2.3 Impact testing

The combination of fibre reinforced plastic skins and a structural foam core, in this design, results in the stiffness providing improved load spreading capability, which, in turn, leads to greater energy absorption per unit shell deflection, as the impact is spread over a greater area of surface foam.

Fig 2 shows the force-deflection response results of helmet shells impacted onto the flat test anvil. The results demonstrate excellent energy management during the first impact event, with the plateau 'g' level being controlled to a level approaching 250 'g', implying a good choice of foam yield stress for this level of load spread.

The results for the second impact event show reduced 'g' levels when compared to the first test. The force at which crushing onset occurs is lower due to shell damage sustained during the initial impact. This reduces the load spreading capability and hence the load required to crush the foam. A second region of crush occurs in these impacts implying that another layer of foam material has started to deform.

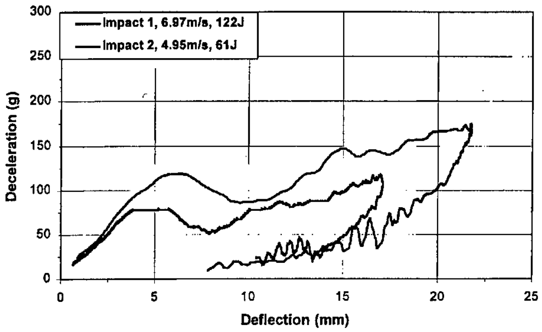

Fig 2: BS6658 Impact Test Using Flat Anvil

Fig 3 shows the force - deflection response for shell impacts, using the Type A hemispherical anvil tests, and show a much decreased crushing load when compared to the flat anvil tests. This is due to a smaller area of foam being crushed because of the concentrated loading. Conventional shell design generally causes the hemispherical impact test to be the most severe, and therefore selection of foam yield stress is based on the impact scenario. The foam selected must therefore be higher density than that required for the flat test due to reduced load spread. Thus the sandwich construction allows the foam to be selected based on the flat test, in the knowledge that the hemispherical test will automatically be passed.

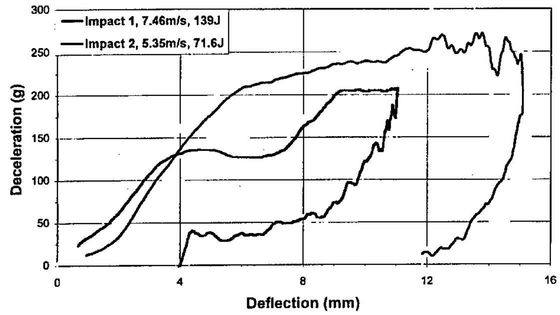

Fig 3:BS6658 Impact Test Using Hemi Anvil

The optimum mass solution for helmet design, based on the pass levels quoted in BS6658 Type A, is therefore not to achieve the lowest possible 'g' level, but to allow the deceleration to rise in a controlled manner, until stable crushing of the energy absorption layers occurs at a level approaching 300 'g'. This design philosophy serves to maximise energy absorption per unit shell deflection, giving the lightest possible shell design to pass the test standard.

However, by a fuller understanding of this design process it would be possible to either maximise protection for a defined helmet mass or to minimise the mass for a defined protection value. Any solution in between is, of course, also achievable.

A comparison of the transmitted impact levels for conventional flying helmets and the lightweight helmet are shown in Figs 4 to 7. For this design of helmet, the philosophy was to provide a helmet lighter than conventional helmets that would provide similar impact performance. In this case the helmet was around 40% lighter than current flying helmets.

BS6658 Type A Impact - Flat Anvil - Rear of Helmet

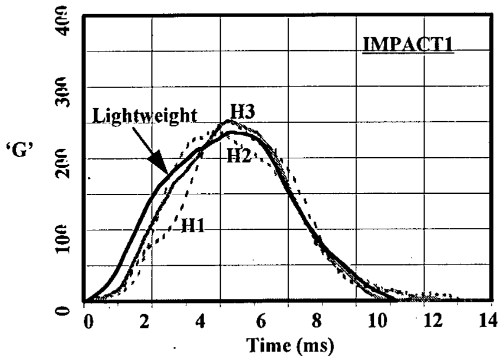

Fig 4: Impact 1

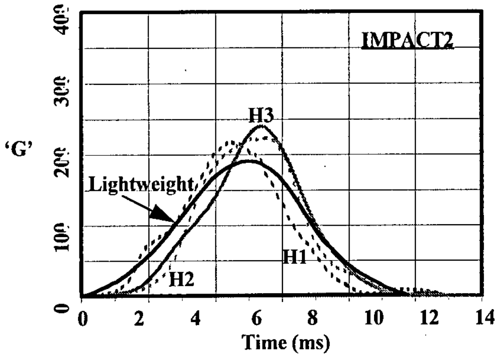

Fig 5: Impact 2

BS6658 Type A Impact - Hemispherical Anvil - Rear of Helmet

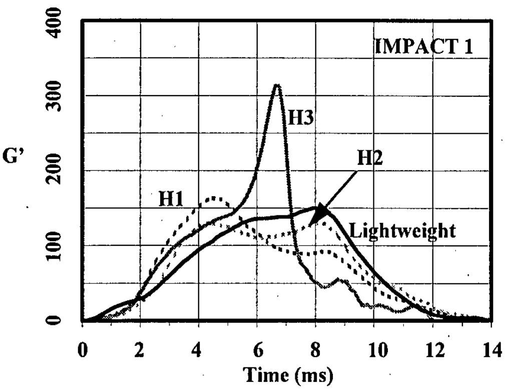

Fig 6: Impact 1

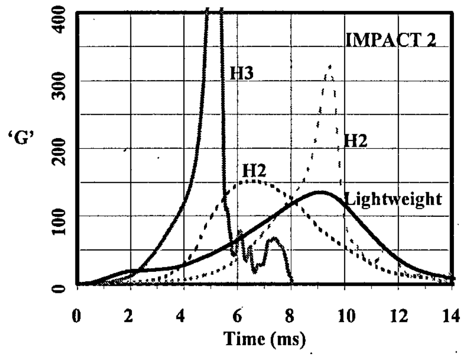

Fig 7: Impact 2

2.4 Modelling

Finite Element Analysis (FEA) of impact behaviour was used in refining the mechanical characteristics of the shell and liner materials and to reducing the dimensions and masses of the impact attenuating liners. Further 3D FEA modelling techniques are being used to model the behaviour of the skull, brain, fluid and cervical spine region to obtain a better understanding of the head under impact

2.5 Head Aggregation and Sizing

To identify methods for defining new size rolls for the helmet, head aggregation and 3D CAD modelling studies were constructed using the head models of 139 male caucasian subjects. Software has been developed to align the heads to form aggregated head models. The individual head scans were landmarked on the screen and the positions of these points were then used to align the whole or sections of each head in the database. The resulting model is known as an aggregation model and represents a volume which encapsulates all of the database members. This aggregation model can then be interrogated within software, using a quasi Gaussian map, to provide summary surfaces at particular percentile positions. Thus, the resulting information is a series of 3-D stacked surfaces, that, for a particular aggregation alignment, describe the percentile sizes of the population. These surfaces can then be used within a 3-D design environment to produce conceptual and production models of future helmet systems. The aggregation criteria and the percentile shell choice can be optimised for the particular application for which the head gear is to be used. Five head registration criteria were used to produce an assessment of the minimum and maximum surface envelopes which enclosed all of the heads in the aggregations.

Currently it is estimated that there may be 2 - 3 sizes for the front section and up to nine for the rear portion.

3. HUMAN FACTORS ISSUES

A series of human factors tests have demonstrated the practical acceptability of some of the component parts of the assembly. Helmet stability, thermal aspects, pressure breathing, noise attenuation, sizing criteria and airflow management aspects were investigated.

3.1 Stability

A series of stability measurements were conducted comparing the stability of form fit liners to those of the current in-service UK helmets. The stability improved in both slippage and torsion, and, although there is a great variation between axes and subjects, a maximum improvement of 15:1 was achieved. The factors which contributed to this variability were estimated to be partially helmet related - support areas etc and partially human related - skin tautness, hairstyles and lengths etc. These improvements in stability will contribute to the reduction in overall head-mounted mass by allowing an optical design that will need a smaller exit pupil. Currently the liners have been perceived by the test subjects as very stable, comfortable, without hot spots and preferable to traditional helmet design. An indication of the stability achieved is shown in the three axes, compared to conventional flying helmets is shown in Fig 8.

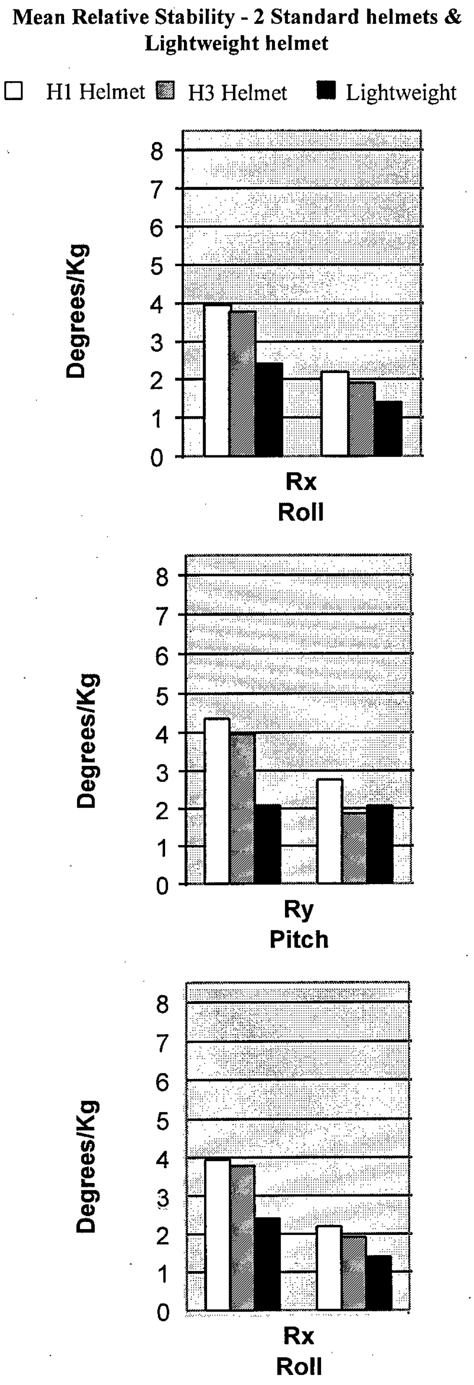

Fig 8:

3.2 Thermal aspects

One obvious concern was the thermal conditions in an enclosed helmet. Motorcyclists, of course, survive in hot climates in helmets of this type, but the application to the airborne environment has greater implications in terms of potential thermal degredation of aircrew performance. An experiment, measuring skin temperatures at five areas of the head, was carried out using subjects exercising sufficiently to double the natural oxygen uptake, each lasting one hour. Thermal build up was measured at three ambient temperatures (20^{0}C, 28^{0}C and 350C). Fig 9 shows the mean head temperatures against time for both the form-fit helmet and a conventional flying helmet. The bars at the end of the plots shows the range of final temperatures.

These levels are in an acceptable range, comparable with a conventional helmet, indicating that, for these cases, additional cooling would not be necessary, but, in the real operational environment, stress levels, physical workload during combat, solar heating etc., may necessitate cooling, and these thermal conditions will be further assessed.

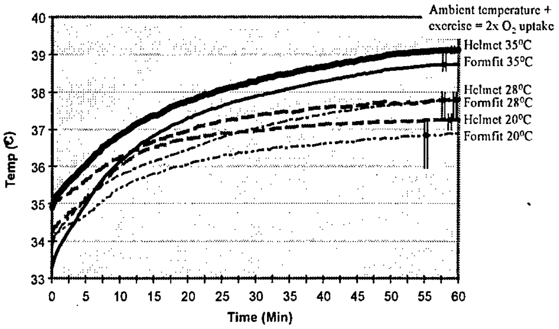

Fig 9: Comparison of Mean Head Temperatures (5 Subjects, 5 Sensors)

In order to provide an acceptable interface between the liner and the skin, a number of materials were assessed, resulting in the mechanical characteristics of traditional kid leather, well known to be acceptable, being chosen. Techniques have been developed to bond the leather to into the high curvature surfaces such as the female moulding of the human head lining, creating a highly acceptable surface for skin contact with little increase in interface pressures with the subjects tested so far and head contact pressures of less than one-third of those in existing UK helmets.

3.3 Pressure Breathing

Although only applicable to fixed wing operations at high altitude, the initial approach and results of pressure breathing trials are reported. The helmet uses a new form of oro-nasal seal which can be used as the moulding around the face was sufficiently accurate to maintain a seal against the face. As a result, simple ori-nasal and ori-maxilo-nasal seals were designed and versions produced in silicone rubber and welded PVC film. A pressure breathing trial was conducted on six subjects and the results show that maximum breathing pressures of 70 mm Hg can be maintained, although with rather high inflation pressures, that is, inflation pressures higher than the test breathing pressure. The oro-maxilo-nasal seal was subjectively considered to be the most comfortable. The use of generically conformal 3-D seals should allow seal inflation pressures to be lower and controlled by breathing pressures, which are related to 'g' levels, and thus eliminate the need for mask tensioning - another component of mass on the helmet.

To complement the seals, lightweight low profile inspiratory and expiratory valves are being developed. The resulting combination, with air passages integral with the shell, eliminate the need for conventional masks, further reducing mass and bending moment about the neck.

3.4 Noise Attenuation

Initial noise attenuation trials have shown that a system integrated into the helmet liner provides some attenuation, but not yet to the level of current aircrew helmets, but the use of lightweight integrated 'shells' and active noise reduction systems, or the use of active noise earplugs (Ref 6), or use of the Communications Ear Plug (CEP) from the USA, would allow acceptable levels of noise attenuation with a suitably lightweight attenuation system.

3.5 NBC Issues

The use of a full face helmet, with suitable sealing at the neck, should allow the NBC protection to be an integral part of the helmet and the current methods of using hoods of the AR5 type to be totally discarded (to the obvious advantage and delight of most aircrew). Aspects such as the need to gain emergency access to parts of the face need to be assessed, but, in reality, any change in philosophy between existing NBC systems and these integrated systems is not expected.

4. HELICOPTER OPERATIONAL APPLICATIONS

Thus Helmet Mounted Displays (HMDs), perhaps of this type, will be integrated into future helicopter systems and many of these systems, particularly battlefield helicopters will have the helmet as an integral part of a Visually Coupled system; that is the sensors, which will provide a picture of the outside world to the aircrew, will be coupled to the HMD with the sensors platform moving in harmony with the pilots head movement. Helicopters of the AH-64 Apache type have such a system in use both for pilotage (PNVS) and for targeting (TADS), and much research is underway as to the optimal FOV, resolution and other technical aspects of the HMDs for helicopter operations. One of the aspects of using HMDs in a weapon system is in the use of off-boresight targeting and the operational benefits accrued. In fixed wing operations significant advantages can be accrued from off-boresight targeting using a helmet sight and target engagement and missile lock-on times reduced by some 60% compared to boresight targeting through a Head Up Display (HUD), with a capability, with a good missile, of firing at up to 60 degrees of boresight. Whilst helicopters can use the high yaw capability inherent in helicopter control to provide a vestige of off-boresight capability, the time taken to stabilise the yaw movement and line up the target will inevitably be longer than using a helmet sight. Thus helmet mounted sights combined with a good missile or gun capability should allow enhanced weapon engagement and release capabilities. A combination of helicopter handling and control, combined with Helmet Sights and/or displays, should allow a significantly improved battlefield capability.

5. HELICOPTER CABIN/COCKPIT NOISE

One of the issues with the helicopter internal environment is the continuing problem of noise levels. The development of new materials to provide lighter airframes, the development of more powerful engines and the increase in lifting/payload capacity form the use of better blade designs has resulted in noise levels in the cockpit and cabin either increasing or remaining essentially constant. Attacking the problem through the use of active devices has proved effective, both operationally and from cost effectiveness. Most systems use the active noise reduction system mounted in the flying helmet, although it is possible to provide area noise reduction in the cabin and this has been accomplished in C130 Hercules trials in the UK. A number of trials have been completed in UK measuring the effectiveness of ANR in helicopters during operational flying. In terms of the reduction of the risk of hearing damage, trials have consistently shown reductions in noise at the ear by around 6dB(A), Ref 2 and around 3.5 dB(A) for trials on a Sea King HAS6, Ref 3. Both of these trials resulted in the noise levels at the ear being reduced to levels that are within the aeromedical guideline limits of 85 dB(A). During all of these trials subjective opinion was sought from the operational crews as to their opinion of the overall effectiveness of ANR. This was accomplished by means of a questionnaire for both aircrew and for the survival equipment crews, who are required to service and support the aircrew equipment. The general aircrew opinion was highly favourable, and the opinions supported the hypothesis that fatigue and stress was reduced, as well as improvements in communications. The effects of stress and fatigue are difficult to measure objectively, and some reliance needs to be placed upon aircrew subjective assessment. Speech intelligibility can, however, be objectively measured in flight and this has been done in a number of flights in the USA and Australia under the auspices of TTCP (AER TP2). Both speech intelligibility direct and other communication parameters such as Speech Clarity, Subjective impression of Speech Intelligibility and Attention Demand are improved. Figure 10 shows data from an Australian Army trial on S-70A-9 Black Hawk (Ref 4).

Aircrew rated the speech heard with ANR in operation as significantly clearer ($p < 0.05$), significantly more intelligible ($p< 0.025$) and significantly less demanding of attention ($p<0.01$) compared to their normal helmet. During these trials noise levels at the ear were taken on the pilot and loadmaster and the mean additional acoustic attenuation provided by the ANR system averaged out at 11 dB(A), reducing the noise at the ear from the helicopter environment down to below 81 dB(A).

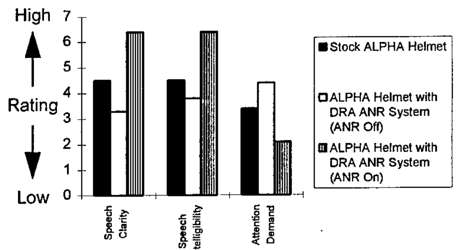

Fig 10: Mean aircrew ratings of speech clarity, speech intelligibility and attention demand (required to understand speech).

Similar results have been measured in the USA in trials on OH 58D, S-70B-2 and EH60 by Simpson (Ref 5) during trials set up, again under the TTCP collaboration. Figs 11 to 14 show a summary of the trials results for all three helicopters. In Fig 11 the in-flight measured speech intelligibility was significantly better with ANR in use and the intelligibility ratings (Fig 12), Clarity ratings (Fig 13) and Attention Demand ratings (Fig 14) were all significantly better with ANR in use across all aircraft.

Speech Intelligibility for Aircrew
Using ANR In OH-58D, Seahawk S-70B-2, and Quickfix EH-60

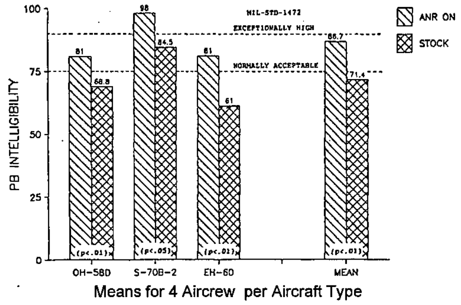

Fig 11:

Speech Intelligibility Ratings by Aircrew
Using ANR In OH-58D, Seahawk S-70B-2, and Quickfix EH-60

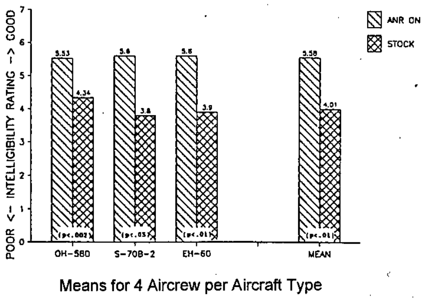

Fig 12:

Speech Clarity Ratings by Aircrew
Using ANR on OH-58D, Seahawk S-70B-2, and Quickfix EH-60

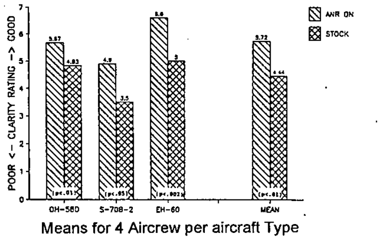

Fig 13:

Attention Demand Ratings by Aircrew
Using ANR in OH-58D, Seahawk S-70B-2, and Quickfix EH-60

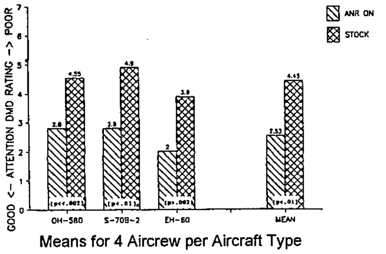

Fig 14:

As part of the new lightweight helmet programme, the use of ear plugs was assessed on the basis that helmet earshells added to the overall mass of the helmet and reductions could be made by reviewing the acoustic attenuation aspects of helmet design. An earplug was designed using an active insert using a similar technology to the circumaural shell ANR technology. The results are shown in Fig 15, Ref 6, and are for an earplug that fits the ear in place of a standard plug (i.e. not a supra-aural device). The results show good attenuation in the 30dB area across the frequency range 160Hz to above 4kHz. In helicopters, where the majority of the high noise generating components are below 1 to 2kHz, these type of active plugs could provide one solution to the invasion of high noise levels.

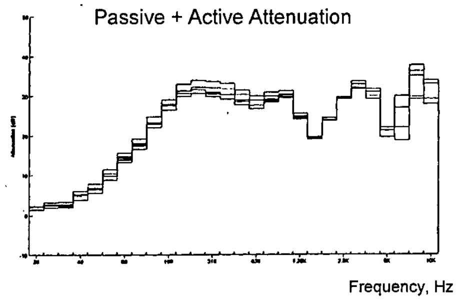

Fig 15: Overall acoustic attenuation for the DERA ANR earplug

A 'supra aural' earplug has been reported (Ref 7) which provides some increased active attenuation in the higher frequencies (i.e. above 1kHz) and the results are shown for this device Fig 16 (from Ref 7).

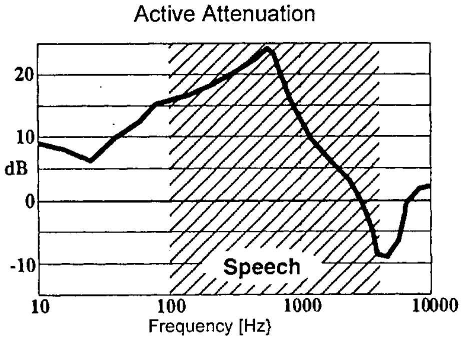

Fig 16: Active attentuation of an experimental ANC ear plug

6. CONCLUSION

If the mass and balance targets of future Helmet Mounted Displays systems are to be met, then it is likely that new approaches to integrated helmet design need to be initiated, as the current approach with conventional flying helmets has obvious limitations. By the use of new materials and structures technology, lighter weight helmets can be designed and built that provide improved impact protection and stability, whilst reducing the risk of neck and spinal injury. Protection against the helicopter noise environment and improved communications can be accomplished by active noise reduction systems which are an integral part of the helmet design and this type of helmet design has the potential for incorporating fully integrated NBC protection .

7. REFERENCES

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Human Factors and Performance Concerns for the Design of Helmet-Mounted Displays

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Summary

Since the 1970s, the trend in Army aviation has been to rely increasingly on helmet-mounted display (HMD) devices or systems to provide the aircrew with pilotage imagery, flight information, and fire control imagery and symbology. Design specifications for future HMDs must be guided by system parameter criteria convolved with hardware limitations, human performance strengths and weaknesses, and good human factors engineering practices. In this paper, past and ongoing research of HMDs is combined to identify potential sources of performance degradation and health hazards. While recognizing the importance of acoustical and biodynamic issues, the major focus here is on optical and visual issues, which include binocular rivalry, fusion, visual illusions, spatial disorientation, and image quality. Related human factors issues also are discussed.

Figure 1. The AH-64 Integrated Helmet and Display Sighting System (IHADSS).

1. Introduction

Since the 1970s, the trend in Army aviation has been to rely increasingly on HMD devices or systems to provide the aircrew with pilotage imagery, flight information, and fire control imagery and symbology. The first such system was the AN/PVS-5 series night vision goggle (NVG), circa 1973. By 1989, the AN/PVS-5 had been replaced by the AN/AVS-6 Aviator's Night Vision Imaging System (ANVIS), the first image intensification (I^2) HMD designed specifically for Army aviation use. When the AH-64 Apache attack helicopter was fielded in the early 1980s, the head-mounted I^2 sensors in NVGs were replaced as the imagery source by a forward-looking infrared (FLIR) sensor, the Pilot's Night Vision System (PNVS), mounted on the nose of the aircraft. Imagery from this sensor is displayed on a miniature 1-inch diameter cathode ray tube (CRT) and optically relayed to the eye. This system is known as the Integrated Helmet and Display Sighting System (IHADSS) (Figure 1). It is a monocular system, presenting imagery to the right eye only. The IHADSS was the first integrated HMD, where the helmet, head tracker, and display were designed as a single system. The success of IHADSS in Army aviation has greatly influenced and contributed to the proliferation of HMD programs [1].

Currently, the Army is developing the RAH-66 Comanche reconnaissance helicopter. This aircraft will utilize a partially overlapped biocular HMD, known as the Helmet Integrated Display Sight System (HIDSS). It consists of an aircraft retained unit (ARU) and a pilot retained unit (PRU). The PRU is the basic helmet with visor assembly. The ARU is a front piece consisting of two image sources and optical relays attached to a mounting bracket. The HIDSS development and validation phase design, which is based on two miniature, 1-inch, CRTs as image sources, provides a 30° (V) by 52° (H) field-of-view (FOV) with a 17° overlap region. However, miniature displays based on flat panel (FP) technologies [e.g., liquid crystal (LC) and electroluminescence (EL)] will very likely replace the CRTs in subsequent program phases.

It is expected that the trend for increasing reliance on HMDs in aviation, as well as in other sectors of the Army, will continue. This paper is intended to serve as both a checklist and a guide for designers of such future integrated helmet and display systems for rotary-wing aircraft. In this paper: 1) salient performance parameters of such systems are identified; 2) recommendations for values of these parameters are suggested, where available, based on past research and the opinions of subject matter experts; 3) human factors engineering and health hazard issues are discussed, and 4) lessons learned from previously fielded U.S. Army HMD systems are summarized. However, this paper is not a cookbook for building an integrated helmet and display system. The design of such a system is strongly dependent on its purpose, user requirements, and the environment within which it is intended to operate.

Melzer and Moffitt [2] describe an HMD as minimally consisting of "an image source and collimating optics in a head mount." For the purpose of this paper, we expand this description to include a visual coupling system, which performs the function of slaving head and/or eye positions and motions to one or more aircraft systems. Figure 2 presents the basic Army aviation HMD as a block diagram in which there are four major elements: image source (and associated drive electronics), display optics, helmet, and head/eye tracker. The image source is a display device upon which sensor imagery is produced. These sources typically have been miniature CRTs or I^2 tubes. Other miniature displays based on FP technologies rapidly are becoming alternate choices. The display optics are used to couple the display imagery to the eye. The optic

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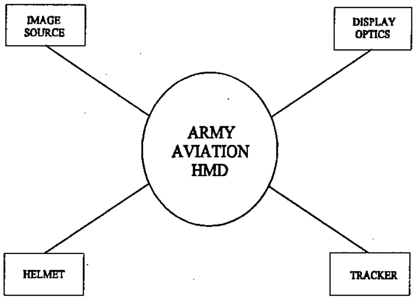

Figure 2. Block diagram of basic Army aviation HMD.

generally magnify and focus the display image. The helmet, while providing the protection for which it was designed originally, serves additionally as a platform for mounting the image source and display optics. The tracking system couples the head/eye line of sight with that of the pilotage sensor(s) (when mounted off the head) and weapons.

An HMD designer must develop a system which is capable of satisfying a large number of widely different and often conflicting requirements in a single system. Such design goals include but are not limited to the following [3]:

- Maximum impact protection
- Maximum acoustical protection
- Maximum speech intelligibility
- Minimum head supported weight
- Minimum bulk
- Minimum CM offset
- Optimum head aiming/tracking accuracy
- Maximum comfort and user acceptance
- Maximum freedom of movement
- Wide FOV
- Minimum obstructions in visual field
- Full color imagery
- Maximum resolution
- High brightness and contrast
- No induced sensory illusions
- Hazard free
- Maximum crashworthiness
- 24-hour, all weather operation
- Minimum training requirements
- Low maintenance
- Low design cost and minimum schedule

From this abridged list of requirements, it becomes apparent that the design of an HMD requires the careful consideration of a multitude of physical parameters and performance factors. In an approach, physical characteristics are replaced by performance figures of merit (FOMs) (Table 1). These FOMs are grouped into natural performance categories: optical system, visual, helmet (with tracking system), and human factors engineering.

2. Visual Coupling

One HMD enhancement to mission effectiveness is the providing of video imagery used for pilotage (most effective during night and foul weather missions). This pilotage imagery is generated from sensors. These sensors can either be head/helmet-mounted, as with ANVIS, or aircraft-mounted, as with the FLIRs on the AH-64 Apache and RAH-66 Comanche. With head-mounted sensors, the resulting imagery is inherently correlated with the direction of head line-of-sight. However, to obtain this spatial correlation for aircraft-mounted sensors, it is necessary to slave the sensor to head motion; the sensor must be "visually coupled" to the head. To accomplish this task, a head/eye tracking system is incorporated into the HMD.

Table 1: HMD performance figures-of-merit [4,5].

Optical system	Prismatic deviation Residual refractive power FOV Percent overlap	Extraneous reflections Biocular channel disparities and misregistration Chromatic aberrations Exit pupil size and shape	Image overlap Static and dynamic MTFs Distortion Spherical/astigmatic aberrations
Visual	Visual acuity Visual field Ocular responses	See-through luminous transmittance See-through color discrimination	Depth perception and stereopsis Illusionary effects Visual problems
Helmet	Head supported weight CM offset Impact attenuation Shell tear resistance Earphone/earcup characteristics Real-ear attenuation	Fitting system characteristics HMD breakaway force Anthropometric fitting range Visor optical characteristics Physical-ear attenuation Speech intelligibility	Tracking accuracy Tracking resolution Tracking system update rate Tracking system motion box size Tracking system jitter
Human factors	Interpupillary distance range Physical eye relief	User adjustments selection and range Equipment compatibility	Training requirements Egress characteristics Fit procedure

2.1 Tracking Systems

Tracking systems with helmet-mounted components must minimize the additional weight, volume, and packaging impacts on the HMD. This is best achieved by using an integrated approach in the HMD design [6]. The various subsystems, e.g., the helmet, optics, etc., still perform their basic functions with minimal compromise to these functions and those of other subsystems. Tracking components which must be helmet-mounted can be modular (add-on), but integrated approaches allow for the imbedding of these components into the helmet shell, thereby optimizing the HMD packaging.

The simplest type of tracking is head tracking, where the position of the head pointing direction is constantly measured. When viewing or tracking objects in the real world, a combination of both head and eye movements is used. [It is an unnatural act to track or point using the head alone. Normal head and eye coordinated motion begins with the eye executing a saccade towards the object of interest, with velocities and accelerations exceeding those of the associated head motion. Consequently, the eye reaches the object well before the completion of the head motion [7].] Eye movements are confined to ±20° about the head line-of-sight. To replicate this viewing mode, more sophisticated visually coupled systems (VCSs) may augment head tracking with eye tracking.

Tracking systems must provide defined measures of accuracy. System parameters include motion box size, pointing angle accuracy, pointing angle resolution, update rate (of tracker, not display), and jitter. The motion box size defines the linear dimensions of the space volume within which the head tracking system (HTS) can accurately maintain a valid line-of-sight. The box is referenced to the design eye position of the cockpit. It is desirable that this box provide angular coverage at least equal to that of normal head movement, i.e., ±180° in azimuth, ±90° in elevation, and ±45° in roll [8]. The motion box size for the AH-64 IHADSS is 12 inches forward, 1.5 inches aft, ±5 inches laterally, and ±2.5 inches vertically from the design eye position. From a human factors viewpoint, it is important that the motion box be able to accommodate multiple seat positions and aviator posture variances.

Pointing accuracy, also referred to as static accuracy, usually means the performance within the local area of the design eye position and for an angular coverage of ±30° in azimuth and ±70° in elevation, i.e., the envelop where the head spends most of its time [8]. In a laboratory setting, current systems can provide excellent static pointing accuracies of 1 to 2 milliradians (mr) (at least in azimuth and elevation, roll accuracy is more difficult to achieve). Measured accuracies in actual aircraft are more typically in the 3 to 4 mr range. Maximum static accuracy is limited by the system's pointing resolution. Pointing resolution refers to the smallest increment in head position (or corresponding line-of-sight angle) which produces a difference in HTS output signal level. One recommendation [4] states that the HTS should be able to resolve changes in head position of at least 1.5 mm along all axes over the full motion box. HTSs also need to provide a specified dynamic accuracy, which pertains to the ability of the tracker to follow head velocities. Dynamic tracking accuracy (excluding static error) should be less than 30 mr/sec.

HTS update rate performance is an often poorly defined parameter. To be useful, update rate must be defined in terms of the sampling rate and the tracking algorithm [8]. Sampling rates of >100 Hz are available. Both IHADSS and HIDSS use a 60 Hz rate. However, if the display update rate is slower than the HTS sampling rate, then these higher rates do not offer an advantage.

Variations in head position output due to vibrations, voltage fluctuations, control system instability, and other unknown sources are collectively called jitter. Techniques to determine the amount of jitter present are extremely system specific.

2.2 System (Lag) Delay

For HMDs where the sensor is helmet-mounted, as with ANVIS, the head and sensor are directly coupled and act as one unit. There is no time delay associated with this coupling. However, for aircraft-mounted sensor systems, the very presence of a VCS implies that there will be a delay between the real world and its presentation [9]. This delay is present because the VCS has to calculate the head positions, translate them to sensor motor commands, and route these commands to the sensor gimbal. Then, the gimbal must slew to the new positions and the display must be updated with the new images. If the magnitude of the delay is large enough, several image artifacts may occur: image flicker, simultaneously occurring objects, erroneous dynamic behavior, and/or multiple images [10].

The natural question is: How fast should the VCS be in transferring head motion to sensor motion and then presenting the new imagery? Its answer depends strongly on the maximum slew rate of the sensor gimbal. The inability of the sensor to slew at velocities equal to those of the aviator's head will result in significant errors between where the aviator thinks he is looking and where the sensor actually is looking, constituting time delays between the head and sensor lines-of-sight. Medical studies of head motion have shown that normal adults can rotate their heads +/-90° in azimuth (with neck participation) and -10° to +25° in elevation (without neck participation). These same studies show that peak head velocity is a function of anticipated movement displacement, i.e., the greater the required displacement, the higher the peak velocity, with an upper limit of 352°/sec [11,12]. However, these studies were laboratory-based and may not reflect the velocities and accelerations indicative of the helmeted head in military flight scenarios [13].

However, VCS lags are not the only delays in the presentation of imagery in HMDs. King [14] cites three types of time lags which must be considered in HMD use: Display lag, slaving lag, and sensor/weapon feedback lag. Display lag is defined as the display latency relative to the current helmet line-of-sight and includes the update rate of the tracker and the refresh rate of the display. Slaving lag is defined as the latency of the sensor/weapon line-of-sight relative to the helmet line-of-sight. This includes the tracker computational time, data bus rate, and physical slaving of the sensor/weapon. Sensor/weapon feedback lag is the latency involved in getting the slave command to the slaving mechanism (gimbal). King [14] provides typical values for these three lags as 50, 650, and 150 msec, respectively.

When discussing time delays in HMDs in the display community, it has been customary to use the term "lag" to mean the time between when the head moves and when the presented image changes to reflect this movement. The frequency at which new display image frames are presented (display refresh) is called the update rate. However, other disciplines do not adhere to this format, and it is wise to precisely define all delay times used with HMDs and VCS.

So and Griffin [15] investigated the effects of lag on head tracking performance using lag times between head movement and target image movement of 0, 40, 80, 120, and 160 msec. They found that head tracking performance was degraded significantly by lags greater than or equal to 40 msec (in addition to a 40 msec delay in the display system). A similar study [16],which investigated the effect of system lag on continuous head tracking accuracy for a task of positioning a cursor on a stable target, found performance effects for lags as short as 20 msec (plus 40 msec display system delay).

The studies cited above, and others [17-19], suggest that there is some uncertainty in maximum allowable time delays, ranging from 40 to 300 msec, depending on task and system. Wildzunas, Barron, and Wiley [20] utilized a NUH-60 Blackhawk simulator to investigate the delay issue under a more realistic military aviation scenario. They tested delays of 0, 67, 133, 267, 400, and 533 msec. The delays were inserted into the simulator's visual display. However, while more representative of rotary-wing flight, the displays were panel-mounted, not head-mounted. While finding some performance effects for delays less than or equal to 267 msec, consistently significant effects were found for the 400 and 533 msec delays.

2.3 Vibration

Helicopters vibrate and any aviator will tell you that is an understatement. This vibration affects both the aircraft and the aviator. Human response to this vibration has been a more difficult problem to understand and solve than that with the aircraft [21]. The effects of vibration manifest themselves as retinal blur, which degrades visual performance, and as physiological effects, whose resulting degradation is not fully understood [22]. Rotary-wing aircraft differ in their vibrational frequencies and amplitudes and these vibrations are triaxial in nature. However, in general, they have a frequency range in all axes of 0.5-100 Hz. However, the transfer function of these vibrations to the eye is not straightforward. The activity of the vestibulo-ocular reflex stabilizes some of the vibrational transfer, mostly low frequency. However, visual performance degradation still will be present. To further complicate this scenario, the vibrational transfer function to the helmet and HMD is different from that to the eye. While the general influencing factors are the same, e.g., posture, body size, etc, the helmet/HMD mass is also a factor. The result is a very complex frequency and amplitude relationship between the eye and the HMD imagery, which results in relative motion between the imagery and the eye [23].

Viewing collimated (infinity focused) HMD imagery should, in theory, eliminate nonangular vibration effects on visual performance. However, investigations of visual performance with HMDs under the relative motion between the display and the eye due to vibration have shown a number of effects. At frequencies below 10 Hz, reading information off the HMD is more difficult than reading off panel-mounted displays [24], up to tenfold at some frequencies. In an investigation of reading HMD symbology numerals, numerals which could be read correctly in 0.4 second while stationary on the ground required 1.0 second in flight [25]. This will result not only in increased error but also increased reaction time.

One final point regarding vibration: Most HMD designs are exit pupil forming systems. They can, in a very loose analogy, be compared to knotholes in a fence. To have an unobstructed view, you must put, and keep, your eye in the knothole. The exit pupil is the HMD's knothole. To prevent vignetting of the full image, the aviator must keep his eye within the exit pupil. If the exit pupil is large enough, additional vibrational effects can be ignored. However, if the exit pupil is small, then the eye may move out of it under the influence of vibration.

2.4 Sensor Switching

The current version of the Comanche HIDSS expects to provide both I^2 and FLIR imagery. While the final decision on whether the I^2 sensor(s) will be aircraft- or head-mounted is yet unknown, the current HIDSS design is based on all sensors being mounted on the aircraft. If, at a later date, a decision is made to mount the I^2 sensor(s) on the helmet, then aviators will be in a situation where they will be switching back and forth between sensor imagery originating from two different perspectives [13]. The human's basic visual sensors are his/her eyes. Prior to encountering aircraft-mounted sensors, his experience in perception and interpretation of visual information has been referenced to the eye's position on the head. When flying the Apache, the imagery often is from the FLIR sensor. This sensor is located on the nose of the aircraft and is approximately 10 feet forward and 3 feet below the aviator's design position. This exocentric positioning of the imagery source can introduce problems of apparent motion, parallax, and incorrect distance estimation [26]. However, this mode of sensor location does offer the advantage of allowing the aviator to have an unobstructed view of the area directly in front of and under the aircraft. This "see-through" capability is very useful when landing must be made in cluttered or unfamiliar landing areas.

If the FLIR remains exocentrically located and the I^2 sensor(s) is integrated into the HIDSS, then additional issues associated with mixed sensor location modes and the resulting switching of visual reference points must be considered. One study [27] looking at these potential issues was conducted using the AH-64 with its exocentrically located FLIR and several HMDs with integrated I^2 sensors. The study found significant degradation in performance for all maneuvers, regardless of direction of switching. Over 80% of the aviators reported that targets appeared to be at different distances as a result of switching, targets in the I^2 imagery appearing closer than in the FLIR imagery. Over a third (37%) of the aviators reported apparent changes in attitude or flight path when switching; three-fourths (75%) stated that switching caused disorientation in one or more of the maneuvers due to switching. And, of most concern, should be the fact that one-half (50%) had to transfer controls to the safety pilot during one of the maneuvers. All of the aviators in the study stated that sensor switching increased workload. In view of these results, careful consideration should be given to HMD designs which require the user to switch between noncollated sensor sources.

3. Optical Performance

In most HMD designs, an image source (e.g., CRT, LCD, etc.) creates on its face a reproduction of the outside scene. This reproduced image then is relayed through a set of optical elements (relay optics) producing a final image which is viewed by the eye. The former image on the image source has certain characteristics. The relay optics have a transfer function which modifies these characteristics in producing the final image. When the aviator dons the HMD, there are both system characteristics (e.g., FOV, magnification, see-through transmittance, etc) and image characteristics (relating to image quality) which define the usefulness of the HMD in helping the aviator perform the mission.

3.1 Image Quality

Farrell and Booth [28] define image quality as the extent to which a displayed image duplicates the information contained in the original scene in a form suitable for viewing and interpreting. [It should be noted that near-infrared (IR) and IR images are not normally viewed images.] To the user, image quality determines his ability to recognize and interpret information. For our purpose, we shall confine our discussion to the system's final image, which is defined by the image source and display optics. Numerous image quality FOMs have been developed and used to evaluate the physical quality of the image produced on a display with the goal of gauging user performance with the display. Task [29] provides an excellent summary of a number of FOMs which commonly are used for evaluating image quality in CRTs. These are listed in Table 2, categorized as geometric, electronic, and photometric.

Table 2: CRT display system FOMs.

Geometric	Viewing distance Display size Aspect ratio Number of scan lines	Interlace ratio Scan line spacing Linearity
Electronic	Bandwidth Dynamic range	Signal to noise ratio Frame rate
Photometric	Luminance Grey shades Contrast ratio Halation Ambient illuminance Gamma	Color Resolution Spot size and shape MTF Luminance uniformity

FP technologies are being used as alternate HMD image sources. Klymenko et al. [30] have categorized FOMs for FPDs into four domains: spatial, spectral, luminance, and temporal (Table 3). These image domains parallel analogous human visual performance domains. The spatial domain includes those display parameters associated with angular view (subtense) of the user and coincide with the user's visual acuity and spatial sensitivity. The spectral domain consists of those parameters associated with the user's visual sensitivity to color (wavelength). The luminance domain encompasses those display parameters identified with the overall sensitivity of the user to illumination levels. The temporal domain addresses display parameters associated with the observer's sensitivity to changing levels of light intensity. [Baron [31] adds two additional domains: depth (3D) and noise.]

Table 3: FPD FOMs.

Spatial	Pixel resolution (H x V) Pixel size and shape Pixel pitch	Subpixel configuration Number of defective (sub)pixels
Spectral	Spectral distribution	Chromaticity Color gamut
Luminance	Peak luminance Luminance range Grey levels Contrast (ratio)	Uniformity Viewing angle Reflectance ratio Halation
Temporal	Refresh rate Update rate	Pixel on/off response rates

In general, these FOMs can be used for image quality evaluation for HMDs since the final image is that of the source image modified by the transfer function of the relay optics. However, there are a few additional FOMs which relate to the system as a whole. The FOMs selected for discussion here are not all inclusive but represent the most critical ones needed to effectively evaluate image quality. However, even for simple HMDs, these FOMs can fail to allow a user to judge between two competitive designs which significantly differ in scope and function [31].

3.1.1 Contrast

Contrast refers to the difference in luminance between two (usually) adjacent areas. There is often confusion associated with this term due to the multiple FOMs used to express contrast [30]. Contrast, contrast ratio, and modulation contrast are three of the more common formulations of luminance contrast. The more common mathematical expressions for luminance contrast include:

$$C = (L_t - L_b) / L_b \quad \text{for } L_t > L_b \quad \text{(Contrast)}$$

$$C_r = L_t / L_b \quad \text{for } L_t > L_b \quad \text{(Contrast ratio)}$$

and

$$C = (L_{max} - L_{min}) / (L_{max} + L_{min}) \quad \text{(Modulation contrast)}$$

where L_t = target luminance, L_b = background luminance, L_{max} = maximum luminance, L_{min} = minimum luminance, and $L_t > L_b$ and $L_{max} > L_{min}$.

Available contrast depends on the luminance range of the display. The range from minimum to maximum luminance values that the display can produce is referred to as its dynamic range. A descriptor for the luminance dynamic range within a scene reproduced on a CRT display is the number of shades of grey (SOG). SOG are luminance steps which differ by a defined amount. They are, by convention, typically defined as differing by the square-root-of-two (approximately 1.414).

Square-root-of-two SOG have been used historically for CRTs, which have enjoyed a position of preeminence as the choice for given display applications for decades. However, within the past few years, the FPD technologies have begun to gain a significant share of the display application market. Displays based on these various flat panel technologies differ greatly in the mechanism by which the luminance patterns are produced, and all of the mechanisms differ from that of CRTs. In addition, FPDs differ from conventional CRT displays in that most flat panel displays are digital with respect to the signals which control the resulting images. (Note: There are FPD designs which are capable of continuous luminance values, as well as CRTs which accept digital images.) As a result, luminance values for flat panel displays usually are not continuously variable but can take on only certain discrete values.

Confusion can occur when the term grey shades, historically used to express the number of discriminable luminance levels in the dynamic luminance range of analog CRT displays, is applied to digital FPDs. Since these displays, in most cases, can produce only certain luminance values, it is reasonable to count the total number of possible luminance steps and use this number as a figure of merit. However, this number should be referred to as "grey steps" or "grey levels," not "grey shades." For example, a given LCD may be specified by its manufacturer as having 64 grey levels. The uninitiated may misinterpret this as 64 shades of grey, which is incorrect. Its true meaning is that the display is capable of producing 64 different electronic signal levels between, and including, the minimum and maximum values, which generally implies 64 luminance levels. If one insisted on using a SOG figure of merit for discrete displays, it would appropriately depend on the value of the 1st and 64th levels.

3.1.2 Contrast and HMDs

HMDs introduce additional contrast issues. For example, in IHADSS, the sensor imagery is superimposed over the see-through view of the real world. Although see-through HMD designs are effective and have proven successful, they are subject to contrast attenuation from the ambient illumination. The image contrast as seen through the display optics is degraded by the superimposed outside image from the see-through component which transmits the ambient background luminance. This effect is very significant during daytime flight when ambient illumination is highest.

A typical HMD optical design in a simulated cockpit scenario is shown in Figure 3. The relay optics consist of two combiners, one plano and one spherical. Light from the ambient scene passes through the aircraft canopy, helmet visor, both combiners, and then enters the eye. Simultaneously, light from an image source such as a CRT partially reflects first off of the plano combiner and then off of the spherical combiner, and then is transmitted back through the plano combiner into the eye. The resulting image is a combination of the modified ambient (outside) scene and CRT images. Nominal values for the transmittances and reflectances of the various optical media are: 70% canopy transmittance; 85% and 18% transmittance for a clear and shaded visor, respectively; 70% transmittance (ambient towards the eye); 70% reflectance (CRT luminance back towards the eye) for the spherical combiner, 60% transmittance (ambient towards the eye) and 40% reflectance (CRT luminance) for the plano combiner.

Ambient scene luminances vary greatly over a 24-hour period. They can range from 0.001 fL under moonless, clear starlight conditions to 10,000 fL for bright daylight. Daytime luminances begin at approximately 300 fL. The image source used in Figure 3 is a miniature CRT. Depending on viewing time, day versus night, luminance values provided by the CRT and its associated optics can be selectively ranged from 10 fL (for night use) to an optimistic 1600 fL (for day use). A luminance of 800 fL may be a more typical daytime value.

Image contrast during night operations is usually not a problem. However, the use of HMDs for daytime imagery (versus for symbology) is not well defined. Based on the design in Figure 3 and the nominal values provided, Table 4 provides the theoretical values for Michelson contrast (C_m), contrast ratio (C_r), and SOG for various combinations of visors, ambient scene luminances, and CRT display luminances. In these equations, the ambient luminance reaching the eye assumes the role of the background luminance and the sum of the CRT and background luminances reaching the eye assumes the role of the target luminance.

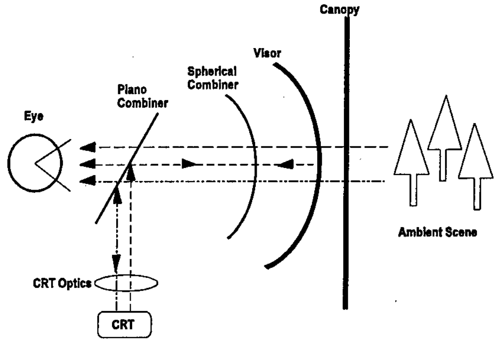

Figure 3. Typical catadioptric HMD optical design.

3.1.3 Contrast Requirements

Once appropriate figures of merit have been established for quantifying contrast, an obvious question is what are their recommended values. Unfortunately, there is no single value or set of values, for minimum contrast requirements. The amount of contrast required to perform a task on a display depends on numerous factors. These factors include the type of visual task (e.g., rapid target detection or status indicators), the viewing environment (e.g., ambient light level, presence of glare sources, the size and distance of the display, etc.), the nature of the displayed information (e.g., text, symbology, video, graphics), and the other display characteristics (such as screen resolution, blur and sharpness, jitter, color, pixel geometry, etc.).

Table 4: Michelson contrast, contrast ratio, and SOG values for an HMD design.

	Ambient luminance					
	3,000 fL		1,000 fL		300 fL	
Display luminance	Clear visor	Shaded visor	Clear visor	Shaded visor	Clear visor	Shaded visor
100 fL	$C_m = 0.01$ $C_r = 1.02$ SOG= 1.06	$C_m = 0.05$ $C_r = 1.11$ SOG= 1.29	$C_m = 0.03$ $C_r = 1.07$ SOG= 1.19	$C_m = 0.14$ $C_r = 1.32$ SOG= 1.80	$C_m = 0.10$ $C_r = 1.22$ SOG= 1.59	$C_m = 0.35$ $C_r = 2.06$ SOG= 3.09
400 fL	$C_m = 0.04$ $C_r = 1.09$ SOG= 1.25	$C_m = 0.17$ $C_r = 1.42$ SOG= 2.02	$C_m = 0.12$ $C_r = 1.27$ SOG= 1.69	$C_m = 0.39$ $C_r = 2.27$ SOG= 3.37	$C_m = 0.32$ $C_r = 1.90$ SOG= 2.85	$C_m = 0.68$ $C_r = 5.23$ SOG= 5.79
800 fL	$C_m = 0.08$ $C_r = 1.18$ SOG=1.48	$C_m = 0.30$ $C_r = 1.85$ SOG= 2.77	$C_m = 0.21$ $C_r = 1.54$ SOG= 2.25	$C_m = 0.56$ $C_r = 3.54$ SOG= 4.66	$C_m = 0.47$ $C_r = 2.79$ SOG= 3.97	$C_m = 0.81$ $C_r = 9.45$ SOG= 7.50
1600 fL	$C_m = 0.15$ $C_r = 1.36$ SOG= 1.89	$C_m = 0.46$ $C_r = 2.69$ SOG= 3.87	$C_m = 0.35$ $C_r = 2.08$ SOG= 3.11	$C_m = 0.72$ $C_r = 6.07$ SOG= 6.22	$C_m = 0.64$ $C_r = 4.58$ SOG= 5.40	$C_m = 0.89$ $C_r = 17.91$ SOG= 9.35

Despite the inability to establish a single set of contrast requirements, a considerable amount of research has gone into determining requirements for viewing and interpreting information in various display scenarios [28,32-33]. For example, for text to be legible on a directly viewed display, it is recommended that the modulation contrast for small characters (between 10 and 20 arc minutes) displayed on a monochrome CRT should be at least that defined by the equation:

$$C_m = 0.3 + [\, 0.07 * (20 - S)],$$

where S is the vertical size of the character set, in minutes of arc [34]. This equation is based on studies by Crook, Hanson, and Weisz [35] and Shurtleff and Wuersch [36].

Fortunately, even with the absence of well defined minimum contrast values, several rules of thumb can be applied. For displayed text, the above recommendation of a minimum contrast ratio value of 3:1, with 7:1 as the preferred value, can be used in benign viewing conditions. For displayed video, a minimum of six SOG is recommended.

3.2. Resolution and Modulation Transfer Function (MTF)

The most frequently asked HMD design question is "How much resolution must the system have?" Resolution refers to the amount of information (detail) which can be presented. This will define the fidelity of the image. Spatial resolution is, perhaps, the most important parameter in determining the image quality of a display system. An HMD's resolution delineates the smallest size target which can be displayed. An image's resolution usually is given as the number of vertical and horizontal pixels which can be presented.

In HMDs using CRTs as the image source, the CRT's resolution is the limiting resolution of the system. The CRT's horizontal resolution is defined primarily by the bandwidth of the electronics and the spot size. Vertical resolution is usually of greater interest and is defined mostly by the beam current diameter and the spreading of light when the beam strikes the phosphor, which defines the spot size (and line width). CRT vertical resolution is usually expressed as the number of raster lines per display height. However, a more meaningful number is the raster line width, the smaller the line width, the better the resolution. Twenty μm is the current limit on line width in miniature CRTs.

In discrete displays such as FPDs, resolution is given as the number of horizontal by vertical pixels. These numbers depend on the size of the display, pixel size, spacing between pixels, and pixel shape [37].

In any optical imaging system, we want the eye to be the limiting resolution factor. At an adaptation level of 100 fL, the eye can detect approximately 1.72 cy/mr (which equates to 20/20 vision). Ideally, the HMD should match or exceed this value. A more realistic, but still optimistic, goal for HMD resolution in the central area of vision is 0.91 cy/mr, with values between 0.39 and 0.77 cy/mr being acceptable [38].

Expressing resolution only in terms of the number of scan lines or addressable pixels is not a meaningful approach. It is more effective to quantify how modulation is transferred through the HMD as a function of spatial frequency. A plot of such a transfer is called a MTF curve. Since any scene theoretically can be resolved into a set of spatial frequencies, it is possible to use a system's MTF to determine image degradation through the system. If the system is linear, the system MTF can be obtained by convolving (multiplying) the MTFs of the system's individual components.

A CRT display's MTF curve typically is a monotonic function, maximum at the lowest spatial frequency present (determined by the display width) and decreasing to zero at the limiting highest spatial frequency of the display (Figure 4). A CRT display's MTF is defined by a number of factors: Scan rate, spot size, phosphor persistence, bandwidth, and drive level (luminance output). Investigations of the effects of these factors for currently used miniature CRTs can be found in Rash and Becher [39] and Beasley et al. [40].

Whether or not the MTF is a meaningful FOM for FPDs is still a point of contention within the HMD community. Biberman and Tsou [22] state that there is no "quantitatively useful" metric for measuring FP technologies which can be related to the MTF. However, Infante [41] provides the following explicit MTF expression for discrete displays:

$$MTF(u) = \left|\left(\sin\pi\sqrt{FF}x_p u\right)/\left(\pi\sqrt{FF}x_p u\right)\right| = \left|(\sin\pi x_a u)/(\pi x_a u)\right|$$

where x_p is the pixel pitch, FF is the fill factor, and x_a is the active pixel size.

Folding in the eyes response is important in assessing the "information transfer" a viewer can achieve. One image quality FOM based on taking the human visual system in consideration is the MTF area (MTFA). The MTFA was developed by Charman and Olin [42] and is pictured in Figure 4. The MTFA is the area bounded by the display system's MTF and the detection threshold curve for the human eye. Theoretically, the greater the MTFA, the greater the information perceived by the eye. The crossover point of the system MTF and the detection threshold curve defines the highest spatial frequency that can be detected (limiting resolution).

The MTFA, however, oversimplifies visual task performance and violates certain mathematical principles. Because of this oversimplification, other image quality metrics have been pursued. Of recent significance is the work of Peter Barten [43-44] and the "Square-root integral" (SQRI) assessment method.

The SQRI is given by

$$SQRI = \int \sqrt{(M(u)/M_t(u))}\frac{au}{u}$$

where M(u) is the MTF of the display, $M_t(u)$ is the visual contrast threshold curve, and u is spatial frequency per unit angle at the eye of the observer. The integration extends over the range from 0 to maximum spatial frequency. As with the MTFA, this equation takes into consideration the spatial frequency description of the display and the human visual system. Good agreement has been found between the SQRI and subjective measures of image quality [43-45].

Most MTF curves encountered are static MTFs, i.e., the modulation in the scene is not changing. However, while static targets relative to the ground do exist on the battlefield, in the aviation environment, relative motion obviously is the more prevalent condition. In addition to the relative target-aircraft motion, when VCSs are used, sensor gimbal jitter and head motion are present. When motion is present, the temporal characteristics of the scene modulation interact with those of the imaging system (e.g., scan rate and phosphor persistence for CRTs) and the transfer of modulation from the scene to the final display image can be degraded.

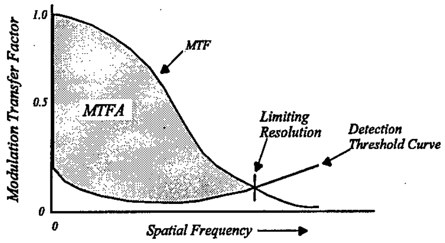

Figure 4. MTF and MTFA.

Phosphor persistence is an important display parameter affecting temporal response in CRT displays. Excessive persistence reduces modulation contrast and causes a reduction of grey scale in a dynamic environment where there is relative motion between the target and the imaging system [46]. Persistence effects can cause the loss of one or more grey steps. This may not be a concern at low spatial frequencies, where there may be multiple grey steps. But, where there is only enough modulation contrast to provide one or two grey steps under static conditions, the loss of even one grey step at high spatial frequencies would be significant.

This effect is well demonstrated in the history of the IHADSS. A P1 phosphor initially was selected to satisfy the high luminance daytime symbology requirement. After initial flight tests, the CRT phosphor was changed to the shorter persistence (1.2 msec) P43 phosphor because of reported image smearing. Test pilots reported tree branches seemed to disappear as pilots moved their heads in search of obstacles and targets. It was determined the longer persistence (24 msec) of the P1 phosphor was responsible for the phenomenon [13].

The degradation in image contrast due to temporal factors is not limited to CRT displays. Active matrix liquid crystal displays (AMLCDs) are currently the leading FP display and are frequently used to present moving imagery [47]. The liquid crystal molecules require a finite time to reorient themselves when the pixel is changing. This is a physical limitation. A response time of 20 - 100 msec is typical. This value is defined by the pixel access time (relatively short, ~65 μsec), crystal's response speed, and other LCD physical properties such as the dependence of cell capacitance on drive voltage and temperature [47-48].

Rabin and Wiley [49] compared visual performance between CRT and liquid crystal displays for high rates of image presentations and found a significant difference, which was attributed to the display response speed. The study involved a target detection task for various horizontal target velocities presented on the IHADSS (using a P43 phosphor image source) and an AMLCD HMD developed by Honeywell, Inc., Minneapolis, Minnesota. Target recognition (contrast sensitivity) was found to be degraded for the AMLCD HMD for the three highest velocities tested (4.4-17.6 deg/sec).

3.3 Luminance Uniformity

Variation in luminance across a display image can be distracting [28]. Luminance uniformity across an image is best described by its absence or nonuniformity [50]. Three important types of nonuniformity are: Large area nonuniformity, small area nonuniformity, and edge discontinuity. Large area nonuniformity is a gradual change in luminance from one area of a display to another; e.g., center to edge or edge to edge. Small area nonuniformity refers to pixel to pixel luminance changes over a small portion of the image. Edge discontinuities occur over an extended boundary.

While uniformity requirements are still lacking in the classical literature, one such guidance is that the luminance at any two points within a flat field image shall not vary by more than 20% [4]. Farrell and Booth [28] suggest limiting small and large area nonuniformities to 10% and 50%, respectively. The HIDSS allows a 20% variation from the mean image luminance, which should be based on luminance readings of at least 9 or more equally spaced positions within the image. [In cases where the entire image area is not useable, variation can be based on only that portion which provides acceptable image quality.]

4. Field-of-View

FOV, as used here, refers to the display FOV, the horizontal and vertical angles the display image subtends to the eye. In terms of impact on performance, FOV can be considered to be as important as resolution and contrast. During night and foul weather flights with HMDs, the largest amount of visual information available to the aviator is provided via the display imagery. In principle, the larger the FOV, the more information available. The maximum FOV target value would be that currently achieved by the unobstructed human visual system.

The human eye has an instantaneous FOV that is roughly oval and typically measures 120° vertically by 150° horizontally. Considering both eyes together, the overall binocular FOV measures approximately 120° (V) by 200° (H) [51]. The size of the FOV that an HMD is capable of providing is determined by several sensor and display parameters including size, weight, placement, and resolution. All of the designs achieved so far provide restricted FOV sizes. As FOVs decrease, head motion becomes greater, increasing head and neck muscle fatigue. This also reduces the amount of background information about the area (target) of interest and induces "tunnel vision" [52].

A number of studies have been conducted in an attempt to understand the role of FOV in pilotage and targeting tasks. Sandor and Leger [53] looked at tracking with two restricted FOVs (20° and 70°). They found that tracking performance appeared to be "moderately" impaired for both FOVs. Further investigation on FOV targeting effects found negative impacts on coordinated head and eye movements [54] and reinforced decreased tracking performance with decreasing FOV size [55-56]. Kasper et al. [57] also examined the effect of restricted FOVs on rotary-wing aviator head movement and found that aviators respond to such restrictions by making significant changes in head movement patterns. These changes consist of shifts in the center of the aviator's horizontal scan patterns and movements through larger angles of azimuth. They also concluded that these pattern shifts are highly individualized and change as the restrictions on FOV change. This work was an extension of Haworth et al. [58] which looked at FOV effects on flight performance, aircraft handling, and visual cue rating.

Perhaps the most important FOV study to rotary-wing aviation is the Center for Night Vision and Electro-Optics, Fort Belvior, VA, investigation of the tradeoff between FOV and resolution [59]. In this study, five aviators using binocular simulation goggles, performed terrain flights in an AH-1S Cobra helicopter. Seven combinations of FOV (40° circular to 60° x 75°), resolutions (20/20 to 20/70), and overlap percentages (50% to 100%) were studied. They reported the lowest and fastest terrain flights were achieved using the 40° - 20/60 - 100% and 40° - 20/40 - 100% conditions, with the aviators preferring the wider (60°) condition. However, the author did not feel that the results justified increasing FOV without also increasing resolution.

Seeman et al. [38] recommend an instantaneous FOV of 50° (V) by 100° (H) for flight tasks involving control of airspeed, altitude, and vertical speed. This estimate does not include considerations for other flight tasks, such as hover. Current HMD programs are striving to produce FOVs of 60° or larger. However, even a 90° FOV does not provide all the visual cues available to the naked eye [60]. Both Haworth et al. [58] and Edwards et al. [61] found that performance gains could be tied to increasing FOVs up to about 60°, where performance seems to encounter a ceiling effect. This raises the question as to whether increased FOV designs are worth the tradeoff costs.

5. Exit Pupil

The exit pupil of an (pupil forming) HMD is the area in space where all the light rays pass; however, it often is pictured as a two-dimensional hole. To obtain the full FOV, the viewing eye must be located at (within) the exit pupil. Conversely, if the eye is totally outside of the exit pupil, none of the FOV is visible. As the viewer moves back from the exit pupil, the FOV will decrease. [The eye has an entrance pupil; when the exit pupil of the HMD is larger than the entrance pupil of the eye, the eye can move around without loss of retinal illumination or FOV [62].]

The exit pupil has three characteristics: Size, shape, and location. Within the limitation of other design confounds, e.g., size, weight, complexity, and cost, the exit pupil should be as large as possible. The IHADSS has a circular 10-mm diameter exit pupil. The HIDSS design exit pupil also is circular but with a 15-mm diameter. While systems with exit pupils with diameters as large as 20 mm have been built, 10 to 15 mm is the typical value [63]. Tsou [9] suggests that the minimum exit pupil size should include the eye pupil (~ 3 mm), an allowance for eye movements that scan across the FOV (~ 5 mm), and an allowance for helmet slippage (± 3 mm). This would set a minimum exit pupil diameter of 14 mm.

The exit pupil is located at a distance called the optical eye relief, defined as the distance from the last optical element to the exit pupil. This term has caused some confusion. What is of critical importance in HMDs is the actual physical distance from the plane of the last physical element to the exit pupil, a distance called the physical eye relief or the eye clearance distance. This distance should be sufficient to allow use of corrective spectacles, NBC protective mask, and oxygen mask, as well as, accommodate the wide variations in head and facial anthropometry. This has been a continuous problem with the IHADSS, where the optical eye relief value (10 mm) is greater than the actual eye clearance distance. This is due to the required diameter of the HDU objective lens and the bulk of the barrel housing. To overcome the incompatibility of spectacles with the small physical eye relief of the IHADSS, the Army has investigated the use of contact lenses [64-66]. While citing a number of physiological, biochemical and clinical issues associated with contact wear and the lack of reliable bifocal capability, the studies did conclude that contact lenses may provide a partial solution to HMD eye relief problems.

6. Monocular/Biocular/Binocular Considerations

HMDs can be classified as monocular, biocular, and binocular, referring to the presentation of the imagery by the HMD. As previously defined, monocular means the HMD imagery is viewed by a single eye; biocular means the HMD provides two visual images from a single sensor, i.e., each eye sees exactly the same image from the same perspective; binocular means the HMD provides two visual images from two sensors displaced in space. [Note: A binocular HMD can use a single sensor, if the sensor is somehow manipulated to provide two different perspectives of the object scene.] A biocular HMD may use one or two image sources, but must have two optical channels. A binocular HMD must have separate image sources (one for each eye) and two optical channels.

6.1 Monocular Issues

Monocular HMDs generally have smaller packaging, lighter weight, and lower design costs. Their smaller packaging permit them to be placed closer to the head, causing less reduction in visual field [67]. Their drawbacks include FOV limitations, small exit pupil, the potential for binocular rivalry, eye dominance problems, increased workload, and reduced reaction time [68]. The reduced FOV [30° (V) x 40° (H) for the IHADSS] results in the need for increased head movements. The small exit pupil size requires the display to be very close to the eye and requires a very stable head/HMD interface. Binocular rivalry causes viewing conflicts between the aided eye viewing the display imagery and the unaided eye viewing the outside world. [Rivalry would be a greater concern in monocular systems where one eye was totally occluded. Such is not the case for IHADSS, where the display eye has see-through capability.] When rivalry does exist, studies have shown that target recognition and visual performance in general decreases [69]. Eye dominance may influence visual performance, of critical interest if the monocular HMD design does not allow for user preference (such as in the IHADSS where the display is always mounted on the right eye).

When Hale and Piccione [70] performed an aviator assessment of the IHADSS, they found evidence of increased workload, visual and mental fatigue, and stress. They found that as a mission progressed, aviators experienced increased difficulty in switching between eyes for visual input. Aviators reported having to resort to extreme actions, such as closing one eye, to either suppress or produce attention switching. Aviators, also, reported visual fatigue from the display "brightness" in the aided eye.

During the first years of fielding the Apache, the training failure rate was high (~10%), and eye dominance was suggested as a probable cause. McLean [71] correlated data on 16 Apache aviators for multiple eye dominance tests. Results showed little correlation between tests. This was explained by the rationale that eye dominance itself is not a singularly defined concept and is task dependent. Also, data failed to show any before and after effects on eye dominance due to PNVS training.

6.2 Biocular/Binocular Issues

As previously discussed, perhaps the greatest disadvantage of monocular HMDs is their reduced FOVs. It is well documented that reduced FOVs degrade many visual tasks [55,72]. In HMD designs, the size (diameter) of the eyepiece lens limits the available FOV.

It generally is agreed that most visual capabilities, e.g., detection, discrimination, recognition, etc., are improved when two eyes are used, as compared to one [73-75]. Using this logic and the FOV argument, current HMD designs are two-eye designs. If an HMD is a two-eye design, there are a number of parameters which must be considered. These include interpupillary distance (IPD), image alignment between the two eyes, and luminance balance [8]. Failure to pay proper attention to these and corresponding issues can result in retinal rivalry, eye strain, fatigue, and, if severe enough, diplopia.

6.2.1 Biocular Tolerances

However, having two optical channels presents the opportunity to have disparities (mismatches) between the imagery presented to the two eyes. These disparities can be alignment errors or optical image differences. Alignment errors reflect lack of parallelism of the two optical axes and can be vertical, horizontal, and/or rotational. Optical image differences can be in contrast, distortion, size (magnification), and/or luminance [62]. These errors will exist. The question is what magnitude of disparity can be tolerated before performance noticeably degrades. These permissible differences are referred to as the optical tolerance limits for the HMD design.

Self [62] provides a review of optical tolerance studies conducted and standards developed before 1986. The results of the review are summarized in Table 5. Also included in Table 5 are more recent tolerance recommendations. It is important to note that users will have varying sensitivities to these tolerances.

Fusion, which is the human visual system's ability to perceive the two images presented as one, is somewhat tolerant. Therefore, some misalignment can be present. Such tolerance limits are not well defined, as can be seen from the wide variation in values in Table 5. Also, it is expected that tolerance limits will vary among individuals and decrease with exposure, fatigue, and hypoxia. The first signs of having exceeded tolerance limits will most likely manifest themselves in the onset of visual fatigue, eye strain, and headaches.

6.2.2 Partial binocular overlap issues

The implementation of partial overlap to achieve larger FOVs brings with it certain additional concerns. Fragmentation of the FOV, luning, and changes in target detection capability can occur in HMDs employing partial overlap [76-78]. If both eyes see the identical full image in a binocular HMD, what is known as a full overlap FOV, then the overall FOV is limited to the size of each of the monocular fields. If for design reasons, the size of the monocular fields are at a maximum and can not be increased without incurring unacceptable costs such as reduced spatial resolution, or increased size and weight of the optics, then the size of the full overlap FOV may not be sufficient.

Table 5: Summary of binocular optical tolerance limits [62].

Vertical misalignment	Horizontal misalignment (Convergence)	Horizontal misalignment (Divergence)	Rotational difference	Magnification difference	Luminance difference
8 arcminutes (2.3 mr) [79]	22.5 arcminutes (6.5 mr) [79]	7.5 arcminutes (2.2 mr) [79]	10 arcminutes [80]	2% [81]	10% [81]
14 arcminutes (4.1 mr) [82]	28 arcminutes (8.1 mr) [82]	14 arcminutes (4.1 mr) [82]	2 degrees [83]	2% [84]	3% [85]
17 arcminutes (4.9 mr) [81]	2 arcminutes (0.6 mr) [85]	4 arcminutes (1.2 mr) [85]	29 arcminutes [28]	< 5% [84]	5% [84]
2 arcminutes (0.6 mr) [85]	8.8 arcminutes (2.6 mr) [86]	3.4 arcminutes (1 mr) [80]		< 0.8% [28]	< 50% [28]
3.4 arcminutes (1 mr) [87]	8.6 arcminutes (2.5 mr) [80]	4.1 arcminutes (1.2 mr) [86]		0.28% [80]	15% [88]
19 arcminutes (5.5 mr) [88]	2.7° (47.1 mr) [28]	3.4 arcminutes (1 mr) [87]		10% [83]	
3.4 arcminutes (1 mr) [80]					

Note: Caution should be used in applying these values since they are based on studies of various optical devices and under different test conditions.

Partial overlap is a way to increase FOV without increasing the size of the two monocular fields. In such a case, the new wider FOV consists of three regions---a central binocular overlap region seen by both eyes and two flanking monocular regions, each seen by only one eye. There are perceptual consequences for displaying the FOV to the human visual system in this unusual way. These perceptual effects have been a concern to the aviation community because of the potential loss of visual information and the visual discomfort [89-93].

First, whereas the full overlap FOV consists of one extended binocular region, the partial overlap FOV consists of three regions, distinguished by how each stimulates the visual system. This can result in the visual fragmentation of the three regions into three phenomenally separate areas, separated by the binocular overlap borders. Since this is a non-veridical perception of what is in reality a continuous visual world, visual misinterpretations may result.

Second, luning may occur in the FOV of partial overlap displays. This is a temporally varying subjective darkening of the flanking monocular regions, most pronounced near the binocular overlap borders. This phenomenon, like visual fragmentation, is due to the nature of the dichoptic stimulation of the monocular regions, meaning that each eye is receiving dissimilar stimulation in corresponding locations, instead of the similar stimulation of normal unaided vision. In this situation, dichoptic competition occurs. Here, the monocular region of the FOV presents a portion of the visual world to one eye and the black background, rather than the visual world, to the other eye. This results in various forms of binocular rivalry, where these inputs compete for awareness with the inputs of each eye alternating in suppressing the input of the other eye. Phenomenally, this is experienced as the darkening effect of luning, which is most prevalent when the eye receiving the wrong image of the black background dominates and suppresses the eye receiving the right image of the visual world.

Third, this competing visual input can result in less detectable targets in the monocular regions of the partial overlap FOV [78]. Melzer and Moffitt [2] have proposed blurring the binocular edges or putting in dark contour lines to separate the binocular and monocular regions to alleviate the detrimental visual effects. In dichoptic competition, sharper edges are stronger competitors than smooth edges [94]. The blurring works by weakening the competitive dichoptic strength of the wrong image, and the placement of dark contours works by enhancing the strength of the right image. Klymenko et al. [95] have confirmed that the placement of contours reduces luning.

In view of these issues, it generally is recommended that full overlap be implemented wherever possible, unless the increased FOV provided by partial overlap is essential [96].

7. Visual Performance

The discussions of physical FOMs above does not attempt to relate the measured values to the visual performance of the user. However, in some cases, it was appropriate to provide limited comments on the impact of the FOMs on user visual performance. In the following sections, system performance as a function of user visual performance is explored in greater depth. The eye has its own transfer function which must be considered when the display image is viewed. Previously, the FOMs for displays were categorized into four domains: Spatial, spectral, luminance, and temporal (Table 3). These image domains parallel analogous human visual performance domains. The spatial domain includes those display parameters associated with angular view (subtense) of the user and coincide with user's visual acuity and spatial sensitivity. The spectral domain consists of those parameters associated with the user's visual sensitivity to color (wavelength). The luminance domain encompasses those display parameters identified with the overall sensitivity of the user to illumination levels. The temporal domain addresses display parameters associated with the observer's sensitivity to changing levels of light intensity.

The human eye has an extraordinary visual capability. It can perceive light within the spectral region of 0.38 μm (violet) to 0.78 μm (red). It consists of a central region, containing cone detectors, which provides detail and color perception (decreasing with decreasing cone density away from the center, fovea); and a peripheral region, containing rod detectors, which provides black and white perception and motion detection. The maximum sensitivity of the cones is about 555 nm and is 507 nm for the rods. The eye has 10 decades of dynamic sensitivity, which usually are divided into three ranges: Photopic (day), mesopic (twilight), and scotopic (night). Adaptation to these varying levels is achieved through photochemical changes and changing pupil diameter from 2.5 to 8.3 mm. The temporal integration time of the eye is about 200 msec. Its resolution capability (for sine waves) is better than 1.72 cy/mr. However, these characteristics vary with age and viewing conditions.

7.1 Visual Acuity

Visual acuity is a measure of the ability to resolve fine detail. Snellen visual acuity commonly is used and is expressed as a comparison of the distance at which a given set of letters is correctly read to the distance at which the letters would be read by someone with clinically normal vision. A value of 20/80 indicates an individual reads letters at 20 feet that normally can be read at 80 feet. Normal visual acuity is 20/20. Visual acuity, as measured through imaging systems, is a subjective measure of the user's visual performance using these systems. The acquisition is a primary performance task. For this task, a reduced acuity value implies the user would achieve acquisition at closer distances. The accepted high contrast acuity value for 2nd and 3rd I^2 systems are 20/60 and 20/40, respectively [13]. However, providing an acuity value for thermal (FLIR) systems is difficult since the parameter of target angular subtense is confounded by the emission characteristics of the target. However, for comparison purposes, Snellen visual acuity with the AH-64 PNVS/IHADSS is cited as being 20/60 [59].

It is well known that visual acuity with I^2 decreases with decreasing night sky illumination [97-99]. Rabin [100] explored the source of this decrease and determined the limiting factor to be the contrast attenuation in the I^2 devices.

7.2 Contrast sensitivity

The human visual system's ability to discern information from a displayed image is limited by its capacity to perceive differences in luminance within the image. These luminance contrasts demarcate the available pattern information of the image. Discounting color and temporal differences, image information is conveyed primarily by patterned contrast. Thus, the information that can be conveyed by a display to a human observer is fundamentally limited by the human ability to perceive contrast. Different magnitudes of contrast are required to perceive different images. For example, the image of a large sharply demarcated object may require less contrast than the image of a small blurry object. If the contrast in an image is too low, i.e., below the visual threshold for detecting contrast, the displayed information will not be perceived. To make appropriate use of the figures of merit describing image quality in terms of contrast, one must characterize the human limitations in detecting contrast. The ultimate goal is to ensure an appropriate match between the contrast in the image conveying the displayed information and the human perceiver's ability to use that contrast.

The smallest magnitude of contrast that can be detected is a just noticeable difference (jnd) between two luminances. A "jnd" is a threshold value that is typically defined as some percentage of the time that a stimulus is correctly detected, often arbitrarily set at 75%. In other words, a jnd of contrast is the threshold magnitude of the luminance difference between two areas that is required to just detect that difference. In order to understand the relevance of the luminances of a display in terms of human perception, the dynamic range of a display, the difference between the maximum and minimum luminances, can be defined, or scaled, in terms of the number of jnds within that range. The number of jnds from minimum to maximum luminance gives us the luminance range in human threshold units [101].

An efficient way of characterizing the contrast threshold responses of the human visual system is the contrast sensitivity function shown in Figure 5, where "contrast" refers to modulation contrast. This plots contrast threshold values as a function of target spatial frequency. Spatial frequency refers to the number of a periodic pattern's repetitions, or cycles, within a unit length. [This unit length is typically expressed as a degree of visual angle when the perceiver is emphasized or as a display width when the image is emphasized.] Contrast sensitivity (on the vertical axis) is the reciprocal of the contrast threshold. The curve indicates that the human visual system is maximally sensitive, i.e., requires the least contrast to detect the pattern's presence, for patterns with a spatial frequency somewhere between 2 and 5 cycles per degree of visual angle. Sensitivity drops off for lower and for higher spatial frequency targets. Sine wave targets smaller or larger than the optimum size need more contrast to be seen.

7.3 Depth Perception and Stereopsis

Depth perception is the ability to estimate absolute distances between an object and the observer or the relative distances between two objects (i.e., which is closer). The cues for depth

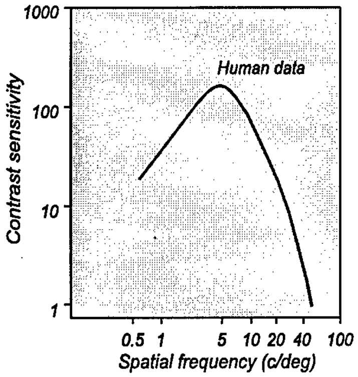

Figure 5. The human contrast sensitivity function.

perception may be monocular and/or binocular. Stereopsis is only a binocular perception and is the result of the two retinae slightly different images of the same object. The differences in the images occur due to the different location of the right and left eyes or the separation between the eyes.

Monocular cues for depth perception include geometric perspective, retinal image size, overlapping contours, shading or shadows, aerial perspective, motion parallax, etc. For Army aviation, motion parallax is considered the most important cue for depth perception. Closer objects appear to move more rapidly than distant objects with increasing displacements from the aircraft line of flight. Another form of motion parallax is referred to as optical flow or streaming.

Stereopsis is a binocular depth perception cue, requiring two slightly laterally displaced inputs for the eyes and sensors. Thresholds for stereopsis have been reported from 1.6 to 24 arcseconds, which is the difference in the eye convergence angles between two objects. For aviators, the passing value for stereopsis with the Armed Forces Vision Tester (AFVT) is 24 arcseconds (group D).

Wiley et al. [102] evaluated depth perception and stereopsis for the unaided eye and with the first fielded NVGs (AN/PVS-5) in both field and laboratory procedures using a modified Howard-Dolman apparatus in the laboratory at 20 feet and the same principle in the field with viewing distances from 200 to 2000 feet. The laboratory Howard-Dolman apparatus consists of two poles where the observer or the experimenter moves one pole to align in depth with a fixed pole, or the observer reports whether one pole is in front of the other with decreasing separation distances. For the field study, the targets were panels (3:1, height to width) and varied in height from 1.75 feet at 200 feet and 17.5 feet at 2000 feet to keep the target size in angular degrees constant. In the laboratory, the unaided photopic binocular threshold for stereo vision was 5 arcseconds and the NVG binocular threshold was approximately 18 arcseconds or similar to monocular unaided vision. Therefore, the conclusion that depth perception was degraded with NVGs implied that there was little or no stereopsis with NVGs. It is interesting to note that in the field study, the unaided monocular threshold was equal to or better than binocular depth perception at any of the tested distances from 200 to 2000 feet, and the NVG stereo threshold, although worse than the unaided thresholds in the field, was better than the unaided stereo threshold obtained in the laboratory.

The Integrated Night Vision Imaging System (INVIS) program attempted to design a night vision I^2 system with lower weight and improved center of mass for fixed-wing aircraft. The objective lenses and intensifier tubes were placed on the side of the helmet with a separation approximately 4 times wider than the average separation between the eyes. This wider than normal sensor separation induced a phenomenon called "hyperstereopsis," which is characterized by intermediate and near objects appearing distorted and closer than normal. The ground would appear to slope upwards towards the observer and appear closer beneath the aircraft than normal. On initial concept flights in an TH-1 helicopter (modified AH-1S Surrogate trainer for the PNVS) at Fort Belvoir, Virginia, pilots found the hyperstereopsis and sensor placement on the sides of the helmet shortcomings (major deficiencies) during terrain flight. The vertical supports in the canopy always seemed to be in the FOV with any head movement, and under starlight conditions, the pilots rated the hyperstereo system unsafe and terminated the study, except for demonstration rides [103].

A hyperstereopsis study was conducted at Fort Rucker, using an "Eagle Eye" NVG with a 2 to 1 increase in IPD, the Honeywell INVIS with 4 to 1 increase in separation, a standard ANVIS, and the FLIR as seen from the front seat in an AH-64 Apache [27]. The results showed no difference in flight performance among the different night imaging combinations. However, the pilots' subjective responses indicated they preferred the ANVIS. Aviators also reported they did not like switching from I^2 to FLIR imagery during landing phases, primarily because of the poor resolution of the FLIR compared to the I^2 devices.

In a recent study, Crowley et al. [104] compared the differences in 13 Army aviators' ability to judge and maintain height above terrain using binocular unaided day vision, 40-degree FOV day vision, ANVIS monocular night time, ANVIS binocular night time, and FLIR (PNVS) monocular night time. Aircraft type was an AH-1 Cobra equipped with an Apache FLIR and extensive data collection capability (radar altimeter). Instrument information or flight symbology on the FLIR image for altitude was removed. The results showed that subjects performed poorly when asked to provide absolute altitude estimates under any condition, but were more consistent in estimating changes in altitude. Performance with the FLIR was consistently worse than with the other viewing conditions. The authors attributed the more variable results with the FLIR to poorer resolution and changing thermal conditions over the 1½- year data collection period.

7.4 Visual Illusions and Spatial Disorientation

Spatial disorientation (SD) is defined by Benson [105] as "the situation occurring when the aviator fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical." Often included in the definition of SD is Vyrnwy-Jones' [106] clause: "the erroneous perception of the aviator's own position, motion, or attitude to his aircraft, or of his aircraft relative to another aircraft." In addition, contact with an obstacle known to be present, but erroneously judged to be sufficiently separated from the aircraft, is included as SD.

One might infer that flight with current night vision devices would induce some SD due to their limitations of reduced FOV, decreased resolution, reduced depth perception, and lack of color vision, as compared to unaided vision. However, at terrain altitudes at night, the aviator has essentially no FOV, resolution, depth perception, or color vision with the dark adapted eye, and could not survive in modern warfare without these night vision devices. Training and improved technology are required to reduce the necessary risks associated with night and adverse weather flying.

In many respects, visual illusions could be considered one of the primary causes of spatial disorientation with night vision devices. Crowley [107] conducted a survey soliciting information from 223 individuals on sensory effects or illusions that aviators had experienced with night vision systems. Frequently reported illusions were misjudgments of drift, clearance, height above the terrain, and attitude. Also reported were illusions due to external lights, and types of illusions were similar for both I^2 devices and the monocular IHADSS, although the sample size for the Apache pilots was small (n = 21). The illumination levels reported when illusions occurred with I^2 devices were below 24% moon, or less, for 36% of the illusion incidents, with lower percentages for incidents with increasing illumination. It would be easy to infer that low illumination was a causal factor, where actually the reverse is true. Illumination below 24% moon occurs 70% of the time for flights beginning 1 hour after sunset and lasting 4 hours. This is the typical Army NVG training mission. The most frequently cited methods to compensate for the illusions were to transfer the controls to the other pilot, use other aircrew to crosscheck visually, and to increase visual scan.

From 1987 to 1995, 37% of the 291 NVG accidents involved spatial disorientation [108]. An analysis of SD accidents of U.S. Army helicopters from 1987 to 1995 found the following results: The types of SD events for night aided flights, listed by frequency of occurrence, were (1) Flight into the ground (28%), (2) drift descent in hover (27%), (3) recirculation (brownout, whiteout, etc.) (22%), inadvertent entry to instrument meteorological conditions (8%), and (4) flight over water (3%) [109-110]. These percentages of SD occurrences were similar for all accidents except the rate for accidents with I^2 devices and FLIR were higher than for day flight. However, it should be noted that all U.S. Army night aided flights occur at 100 feet above ground level (AGL) or less except when transitioning to and from the primary airfields. This low altitude reduces reaction time and increases the risks compared to day and night general flight profiles. The 1987-1995 SD study [109] also found that very few illusions actually caused SD accidents.

7.5 Visual Problems

The use of HMDs increases visual workload and, very likely, raises stress levels among users. After several years of fielding the AH-64 Apache, a survey of Apache aviators [70] documented reports of physical fatigue and headaches following flights using the monocular IHADSS HMD. This followed anecdotal reports of similar problems from instructor pilots at Fort Rucker, Alabama. Hale and Piccione [70] cited as possible causes: binocular rivalry, narrow FOV, poor depth perception, inadequate eye relief, and overall system discomfort. To investigate potential concerns of long-term medical effects of using the IHADSS, the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, conducted a three-part study [111]. The first part was a written questionnaire which served the purpose of documenting visual problems experienced by the local Fort Rucker, Alabama, Apache aviator community. The second part was a clinical and laboratory evaluation of the refractive and visual status of a sample of these aviators. The third part was an assessment of the diopter focus settings used by aviators in the field environment. Since the IHADSS is designed to have the virtual imagery appear at optical infinity, incorrect diopter focus settings could, in theory, lead to visual fatigue and related visual problems.

A total of 58 Apache aviator questionnaires were completed. More than 80% of the sample aviators reported at least one visual complaint associated with flying with the IHADSS. A summary of complaints is provided in Table 6 [111]. The most common complaint (51%) was that of "visual discomfort" during flight. Approximately a third of the aviators reported occasional headaches, and about 20% reported blurred vision and/or disorientation while flying. The percentage of aviators reporting headache and blurred vision after flying remained about the same, while the percentage of those experiencing disorientation after flying decreased to 5%.

The clinical and laboratory evaluation of the refractive and visual status of 10 aviators found no statistical correlation between visual performance and visual complaints. There were no significant differences found between right and left eye performance. There was evidence of mild incipient presbyopia in a majority of the aviators, but this was within expectations for the sample age range. Binocular ocular motility for the sample was found to be lower than expected. But, in summary, the study concluded there was no significant variation from normal performance values noted.

The diopter focus settings of 20 Apache aviators (11 students and 9 instructor pilots) were measured in the aircraft following their normal preflight setup. Nine were measured under nighttime illumination conditions and 10 under daytime conditions. A range in focus settings of 0 to -5.25 diopters (mean of -2.28 diopters) was obtained. It was concluded that the required positive accommodation by the eye to offset these negative focus settings was a likely source of headaches and visual discomfort during and following long flights. No correlation was found between the focus settings and aviator age or experience; nor were there differences between instructor pilots and students, or day versus night.

In another survey [107] of 242 aviators flying either ANVIS (rotary- and fixed-wing) or IHADSS, a very small percentage of the rotary-wing ANVIS users (n = 212) reported physiological effects to include eyestrain (3%), headache (2%), motion sickness/vomiting (2%), postflight blurred vision (1%), and dizziness (1%); only 5% of Apache aviators (n = 21) reported any visual problems (that of dark adaptation effects).

The move towards two-eyed (binocular) wide FOV HMDs may result in adverse visual effects if care is not taken in their design. Mon-Williams, Wann, and Rushton [112] point out that conflicts between accommodation and vergence, focal error, and prismatic errors may result in "unstable binocular

Table 6: Apache aviator reports of visual complaints during and after flight [111].

Complaint	During flight			After flight		
	Never	Sometimes	Always	Never	Sometimes	Always
Visual discomfort	49 %	51 %	--	70 %	28 %	2 %
Headache	65 %	35 %	--	67 %	32 %	2 %
Double vision	86 %	12 %	2%	89 %	9 %	2 %
Blurred vision	79 %	21 %	--	72 %	24 %	3 %
Disorientation	81 %	19 %	--	95 %	5 %	--
Afterimages	NA	NA	NA	79 %	19 %	2 %

vision." As previously discussed, failure to maintain strict binocular alignment may introduce serious performance problems.

8. Conclusions

HMDs are continuing to expand their role and presence in the aviation community. It has been shown that HMDs provide unique and necessary capabilities to night and foul weather operations. It is the believed that this trend will continue.

Perhaps, the best design approach for HMDs is an integrated one, where the HMD is designed from the ground up, addressing the combined issues of acoustics, biodynamics and vision. The less preferred approach is that of adding the optical section of the HMD design to an existing helmet platform. This usually results in performance compromises.

The performance of an HMD depends on multiple factors, which include acoustical (e.g., sound attenuation, speech intelligibility, etc.), biodynamic (e.g., head supported weight, center of mass, impact attenuation, etc.), and optical (e.g., distortion, power, magnification, etc).

While not necessarily of greater importance, HMD visual and optical design concerns have been identified and presented with an emphasis on impact on visual performance. As HMD designs move from the monocular IHADSS to the binocular HIDSS, issues of fusion, alignment, etc. require greater emphasis.

Disclaimer

The views, opinions, and/or findings contained in this paper are those of the authors and should not be construed as an official Department of the Army position, policy, or decision.

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Effects Of Head-Supported Devices on Female Aviators During Simulated Helicopter Rides

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SUMMARY

Researchers at the U.S. Army Aeromedical Research Laboratory (USAARL) recently concluded that weight-moment of head-supported devices (HSDs) worn by male aviators should not exceed 80 Newton-centimeters (N-cm). The goal of this study was to define a safe range of weights and centers of mass of HSD that can be tolerated by female helicopter pilots without affecting their health or degrading their performance. Five subjects were exposed to whole-body vibration while wearing HSD with various mass properties. During exposure, biomechanical head acceleration response was recorded. Head pitch, anterior-posterior, and axial accelerations were measured for 12 different helmet configurations during sinusoidal vertical vibration having a magnitude of 0.45 m/s^2 and frequencies swept from 2 Hz to 17 Hz at the rate of 0.25 Hz/sec. Preliminary results indicate that head pitch and axial acceleration levels for female subjects were lower than those for their male counterparts. This may be attributed to gender differences in upper-body anthropometry. The standard deviation of female head accelerations was found to be similar to that of male subjects.

LIST OF SYMBOLS

AP	anterior-posterior
AOC	atlanto-occipital complex
C0, C1, C2	cervical vertebrae
CM	center of mass
cm	centimeter
EAM	external auditory meatus
G	acceleration due to gravity
HSD	head-supported devices
Hz	Hertz, samples/second, cycles/second
LED	light emitting diode
MARS	multi-axis ride simulator
MPF	mean power frequency
PSD	power spectral density
RMS	root mean-square
WBV	whole-body vibration
USAARL	U.S. Army Aeromedical Research Laboratory

1. INTRODUCTION

Aviators flying rotary-wing aircraft are exposed to whole-body vibration (WBV) transmitted primarily through the seating system causing musculoskeletal stress to the back and neck. These stresses are aggravated when the head is further loaded with a helmet and other head-supported devices (HSDs) such as night vision goggles. New HSDs and improvements in crash protection technology and materials have altered the mass properties of modern aircrew helmet to an extent where existing operational and design criteria may no longer apply.

Safe and tolerable limits of HSD mass properties, such as mass location and distribution are important design criteria for future aircrew helmets. The obvious challenge for the Army research community is to establish those safe limits for HSD mass properties that can be tolerated by male and female aviators alike.

A series of studies have been conducted at the U.S. Army Aeromedical Research Laboratory (USAARL) to evaluate the effects of HSD mass properties on pilot biomechanical, physiological and performance responses [1-3]. Butler [1] showed a significant increase in head pitch acceleration response when the total head-supported load exceeded 83 N-cm relative to the atlanto-occipital complex (AOC). The AOC is a functional anatomic structure that represents the C0-C1-C2 joints of the upper cervical spine [4]. Butler also showed no difference in head pitch acceleration response for the unloaded (no helmet) case compared to the helmets with a weight moment less than 83 N-cm.

Alem et al. [2] studied performance of male pilots under long exposure (up to 4 hours) to WBV and under four HSD configurations. They demonstrated that the subject's reaction time to a randomly appearing target significantly increased as the weight moment of the helmet increased beyond 78 N-cm. Another USAARL study showed significant changes in electromyography responses to HSD loading under WBV [3].

These USAARL studies concluded that the HSD weight moment should not exceed approximately 80 N-cm. Since this conclusion was derived from laboratory experiments with male volunteers as subjects, it was reasonable to expect that the limit should be different for female aviators because of known gender differences in neck size, upper body anthropometry, and physiology.

The main objective of the present study was to identify safe limits of HSD weight moments that can be tolerated by female aviators without adverse effects on their health

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and performance. Our approach was to measure and assess biomechanical, cognitive, physiological, and performance parameters associated with the exposure of female subjects to simulated helicopter vibration signatures and different helmet configurations. The study design requires a sample size of 12 subjects. Analysis of only 5 subjects has been completed. Therefore, these results should be considered preliminary. Furthermore, only the biomechanical measurements are presented in this paper.

2. METHODS

2.1 Subjects

Five subjects aged 31.6 (± 5.3) were recruited without coercion or bias. Subjects were limited to non-aviation active duty females to avoid mixing subjects with different levels of helmet experience. In order to eliminate controllable sources of variation in the sample, the following subject selection criteria were applied:

- Body weight must be within Army standards for height and age.
- Must not participate regularly in specific neck and upper-body strengthening exercises.
- Must not have any significant medical condition as judged by the flight surgeon.

2.2 Instrumentation

Simulated HSD Platform

To simulate various HSD weight moments, a modified aviator helmet was utilized for this study. This helmet allowed the investigator to vary weight and center of mass (CM) precisely and rapidly. The helmet was calibrated for 5 weights (1.4 to 4.1 kg) and 21 center of mass locations (in the x, y, and z planes). This HSD simulator was used for male subjects in previous USAARL experiments and found to be adequate [1-3]. The appropriate locations of the weights were determined according to the method developed by Barazanji and Dodson [6].

Accelerometers/Bite Bar

Under WBV exposure, the head moves in a natural nodding motion in the mid-sagittal plane. That is, the motion consists of two translations (axial and anterior-posterior) and a pitch rotation about the left-right axis. Since this was a three-degrees-of-freedom motion, at least three independent accelerometer readings were necessary to solve the kinematics problem. However, a fourth redundant accelerometer was added to simplify the equations and to obtain a robust solution. Thus, four miniature uni-axial accelerometers were mounted strategically on a bite bar (Figure 1).

The bite bar consisted of a precision-machined, lightweight, aluminum alloy mount approximately 12 cm long and attached to a U-shaped bite plate. This bite plate was fitted to the subject's teeth using dental molding compound a day prior to testing. The accelerometers (Entran model EGAXT) each measured nearly 5 x 4 x 8 mm with a dynamic range of 150 m/s^2. The bite bar was used only during the swept sine vibration testing as explained below in the Procedures section.

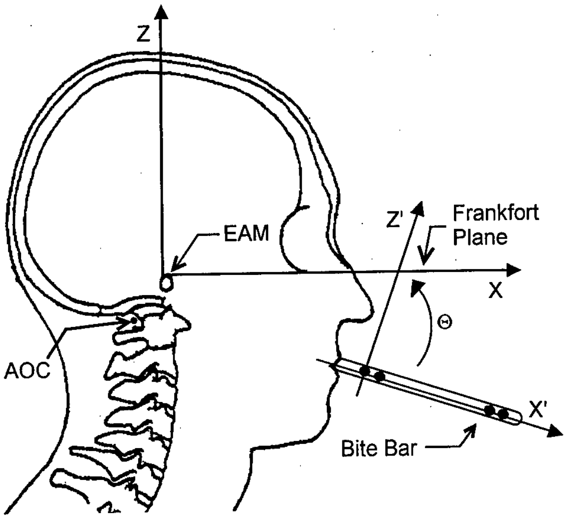


Figure 1. AOC location with respect to EAM. EAM represents origin of the anatomical coordinate reference system XZ. θ is a pitch angle relating the bite bar coordinate system X'Z' to XZ. Filled circles on the bite bar represent locations of accelerometers. The X and Z axes denote the AP and axial directions, respectively.

Photogrammetry

Bite bar position was acquired using the Optotrak (Northern Digital, Inc.) three-dimensional (3D) position measurement system. This system operates by triangulating on pulsed infrared light emitting diode LEDs, and yields 3D coordinates for each LED relative to a user-selected viewing position. Two LEDs were added to the bite bar to measure bite bar position during the swept sine session. From the position measurements, the contribution of gravity (1G) can be subtracted from the acceleration measurements.

2.3 Procedures

General Approach

The general approach of the study was to measure head acceleration of female subjects in response to swept sine vibration and for 12 helmet configurations. This type of vibration allowed a systematic method of determining the biomechanical response of the head under loading.

The subjects were exposed to the helmets based on a counterbalance design. Subject 1 was tested according to the generalized sequence H_1 H_2 H_n H_3 H_{n-1} H_4 H_{n-2} H_5 etc., until convergence ($H_\#$ = helmet configuration number, n = total number of helmets). That is, subject 1 was presented first with H_1, followed by H_2 H_{12} H_3 H_{11} H_4 H_{10} H_5 H_9 H_6 H_8, and H_7. Subject 2 was presented with the subsequent helmets, first with H_2, followed by H_3, H_1, H_4, H_{12}, H_5 etc. Subjects 3-5 had similar sequences and subject 6, when recruited, will have also a similar sequence. Subjects 7-12, however, will be presented with the reverse order of helmet sequences that of subjects 1-6. The rationale behind this arrangement is to present an equally balanced helmet presentation among all subjects without bias. In addition, the number of helmets (n=12) was chosen to allow comparisons to a similar study by Butler [1] that used the same HSD configurations on male subjects and showed significant levels.

The total number of subjects (n=12) was based on a statistical design that has at least a 90% chance of achieving significant agreement between independent variables (weight moment) and dependent variables (head pitch acceleration or performance time responses) [7]. Since each helmet test under swept sine took approximately 2 1/2 minutes, all 12 HSD configurations were tested in a single day. A no-helmet session always preceded the 12 helmet sessions for each subject.

The actual locations of helmet CM relative to head CM were measured with a mass properties instrument [6]. The head CM location relative to head AOC is known for male subjects [1]. This location was multiplied by a ratio of 0.95 to reflect gender differences in head breadth and head length [8]. Thus, the actual locations of helmet CM with respect to head AOC were estimated as shown in Table 1. The helmet weight moments were calculated from the values in Table 1 (i.e., weight moment [N-cm] = 9.806 [m/s^2] × mass [kg] × helmet CM relative to AOC in the AP direction [cm]).

On a day prior to testing, the subjects were briefed on the testing procedure and signed a Volunteer Agreement Affidavit. Also, a lateral x-ray of each subject's head was taken with the bite bar in her mouth. Radio-opaque pellets were used to mark the infra-orbital notch and the external auditory meatus (EAM). From the x-ray, the Frankfort plane-based anatomical reference frame was determined as shown in Figure 1. Also, the coordinates of the bite bar accelerometers with respect to the head AOC were measured.

The subject was seated in the UH-60 seat attached to the MARS platform. The bite bar was held rigidly in the subject's mouth during the test. Before each vibration session, the subject was asked to sit in a relaxed position.

Table 1. Helmet mass and center of mass location for the swept sine vibration exposure

Mass (kg)	Center of mass forward distance relative to the AOC (cm)			
2	0.95	3.24	5.18	6.81
3	0.97	3.10	5.21	7.31
4	1.05	3.32	5.28	7.24

Sinusoidal Whole-Body Vibration

WBV exposure was conducted on the USAARL man-rated multi-axis ride simulator (MARS) platform, to which a UH-60 seat was attached. Vibration levels did not exceed the exposure criterion for safe operation established by International Standards Organization guideline [5]. Input sinusoidal vibration was in the axial (vertical) direction and increased from 2 to 17 Hertz at the rate of 0.25 Hertz per second, then decreased back to 2 Hertz at the same rate (Figure 2). A constant peak acceleration of 0.35 G was maintained. The entire up/down sweep took approximately 2 minutes.

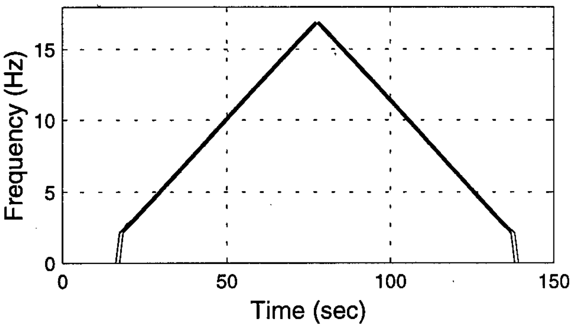


Figure 2. Frequency response of platform axial acceleration as a function of vibration exposure time for subject 3 over 12 helmet loads.

3. DATA ANALYSIS

Most of the data analysis was performed using Matlab, a high-performance language of technical computing [9]. The acceleration signals were calibrated and low pass filtered at 20 Hz. A Butterworth low pass filter was designed based on the power spectral density (PSD) of the bite bar acceleration. As expected, 97% of the signal energy (i.e., the area under the PSD curve) occurred below 17 Hz, which is the highest input sinusoid frequency.

The filtered data were then resampled from 1000 Hz to 100 Hz so that they were compatible with the Optotrak sampling frequency of the bite bar position measurements. The bite bar pitch angle during the sinusoidal vibration was determined from the Optotrak position measurements. Using the pitch angle, the contribution of earth gravity (9.81 m/s^2) was subtracted from the resampled acceleration data.

Because of the exact registration with the subject's teeth, the head-bite bar system can be considered a rigid body, allowing the use of rigid-body kinematics to compute the linear and angular accelerations of the head motion in the mid-sagittal plane. Two standard kinematics translations were applied to the "gravity-free" bite bar accelerations: a linear translation from the bite bar to the head EAM in the axial and AP directions and a pitch rotation about the left-right axis [10]. From the x-ray, the axial and AP distances from the accelerometers to the EAM and the pitch angle between the bite bar reference frame and the Frankfort plane-based anatomical reference frame were determined (Figure 1). The x-ray readings and kinematic equations allowed pitch, axial, and AP accelerations of the head to be computed. To compare current findings with findings of the Butler study [1] done on male subjects, head accelerations were determined at the AOC.

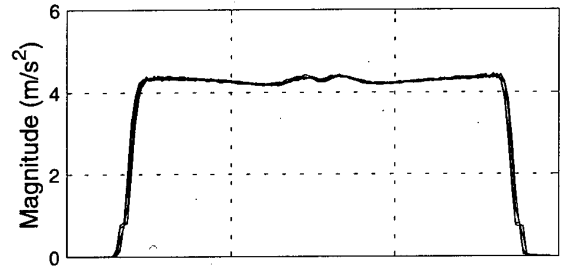
Spectral analysis using the fast Fourier transform method was utilized to convert the time domain response of the platform acceleration, and head pitch, axial, and AP accelerations into the frequency domain. The mean power frequency (MPF) of the platform acceleration, and the root mean square (RMS) of the head accelerations were computed. The peak magnitude at resonance was determined from the head RMS response, and the resonant frequency was determined from the platform MPF for different helmet configurations.

4. RESULTS

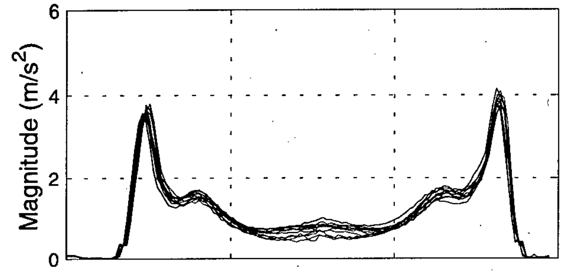
Figure 3 shows the magnitude responses of the platform acceleration and the head accelerations of subject 3 for 12 helmet configurations. Note the symmetry in responses between ramp-up and ramp-down phases of the swept sine vibration among all helmet configurations.

In Figure 4, the magnitude of subject 3's response was averaged for both phases of vibration and plotted against the input frequency of platform acceleration. All subjects exhibited similar responses.

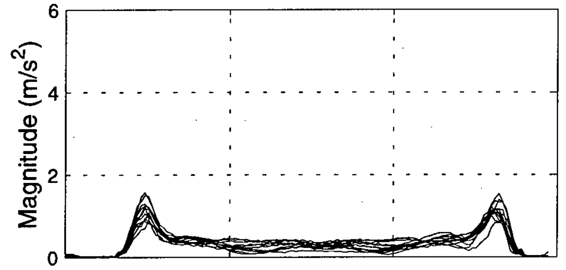
(a) Platform Acceleration



(b) Head Axial Acceleration



(c) Head AP Acceleration



(d) Head Pitch Acceleration

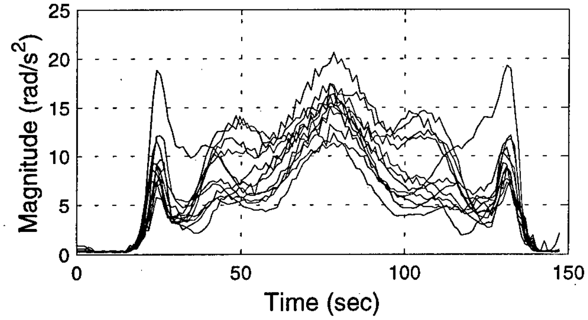
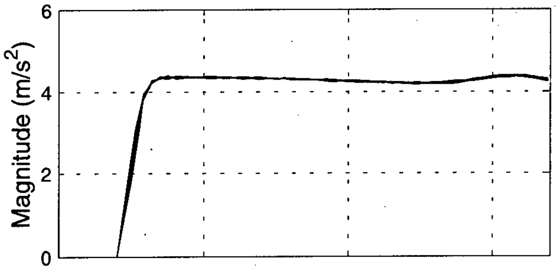
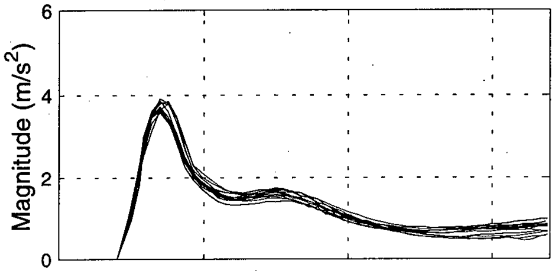


Figure 3. Platform axial (a), head axial (b), head AP (c), and head pitch (d) accelerations as functions of vibration exposure time for subject 3 over 12 helmet loads. Magnitude represents the RMS of acceleration.

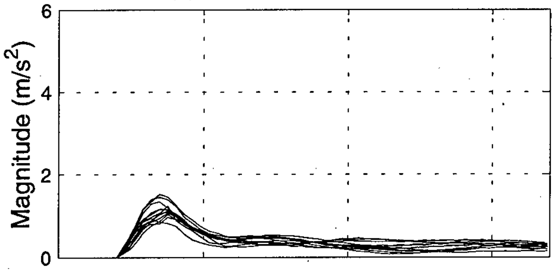
(a) Platform Acceleration



(b) Head Axial Acceleration



(c) Head AP Acceleration



(d) Head Pitch Acceleration

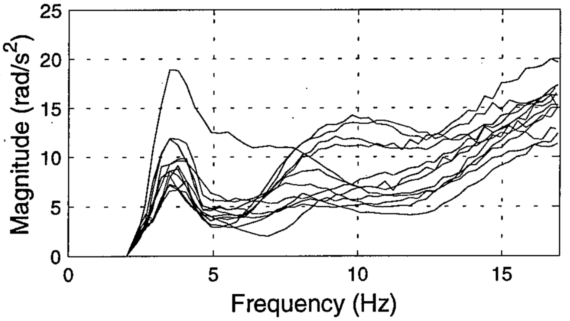


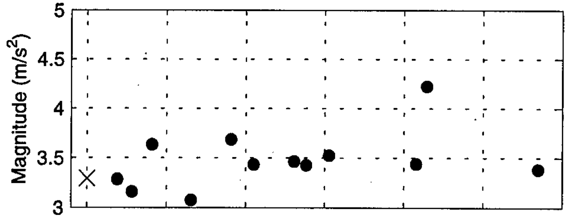
Figure 4. Platform axial (a), head axial (b), head AP (c), and head pitch (d) accelerations as functions of platform vibration frequency (input) for subject 3 over 12 helmet loads. Magnitude represents the RMS of acceleration.

Although there was more than one resonant frequency, the first one was considered for this analysis because it was the most dominant. The first resonant frequency and its magnitude were extracted for each helmet load and for each subject. The resonant frequencies ranged from 3.5 – 4.5 Hz for all accelerations among all helmets, and for all subjects (n = 4). The resonant magnitude for each head acceleration was averaged among all subjects.

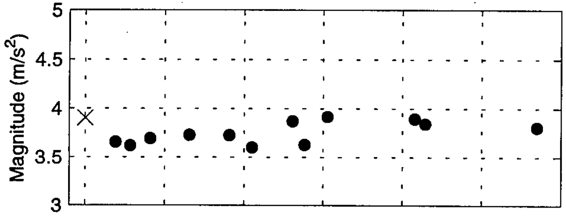
The bite bar position was not measured during testing of the first subject, so it was not possible to correct the acceleration measurements for gravity. Thus the analysis was done on measurements of four subjects only. Figures 5, 6, and 7 show the resonant magnitude of head axial, AP, and pitch accelerations for each subject, and the averaged magnitude with respect to helmet weight moment relative to AOC.

Head Axial Acceleration

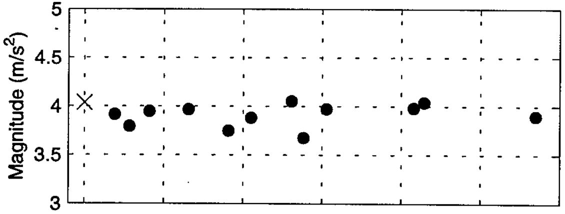
(a) Subject 2



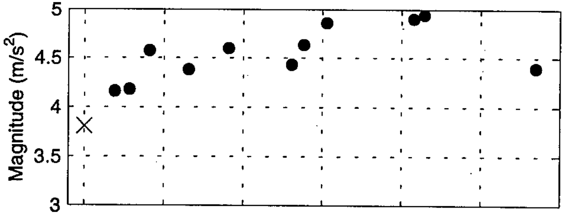
(b) Subject 3



(c) Subject 4



(d) Subject 5



(e) Average

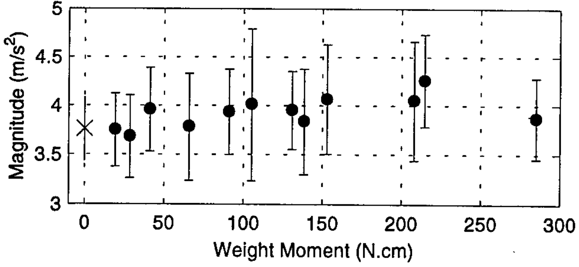
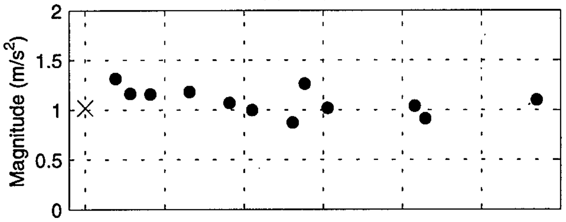


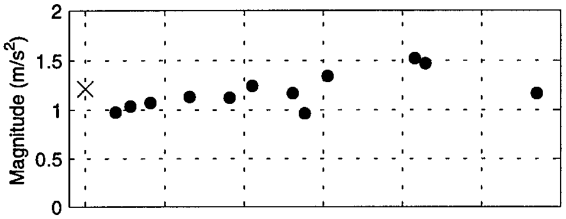
Figure 5. Magnitude of head axial acceleration at first resonant frequency for subjects 2-5 (a-d). The axial magnitude was averaged among the four subjects as a function of weight moment (e). The symbol • represents the loaded cases and × represents the unloaded case. Error bars are ± 1 SD.

Head AP Acceleration

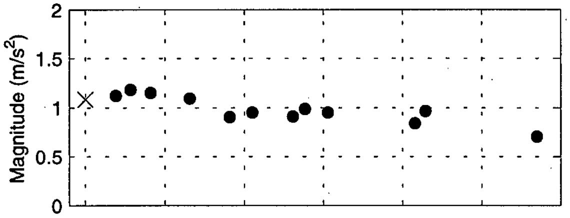
(a) Subject 2



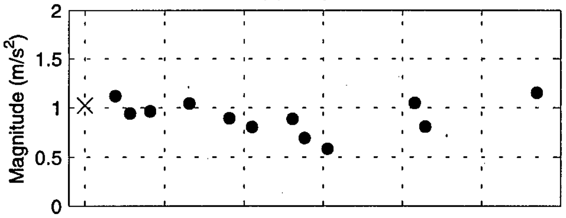
(b) Subject 3



(c) Subject 4



(d) Subject 5



(e) Average

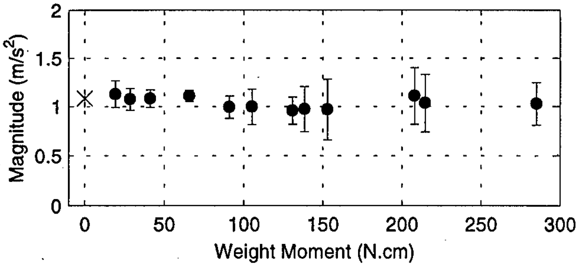
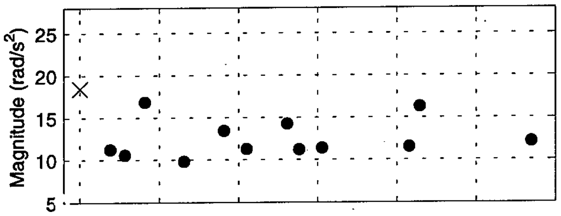


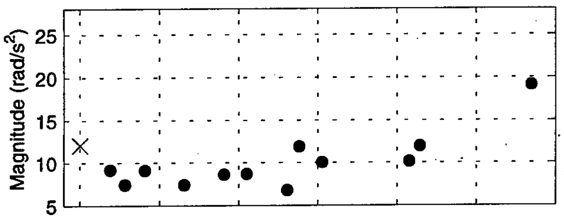
Figure 6. Magnitude of head AP acceleration at first resonant frequency for subjects 2-5 (a-d). The axial magnitude was averaged among the four subjects as a function of weight moment (e). The symbol • represents the loaded cases and × represents the unloaded case. Error bars are ± 1 SD.

Head Pitch Acceleration

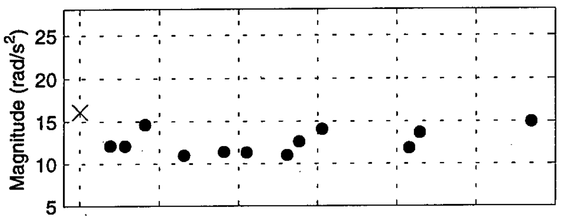
(a) Subject 2



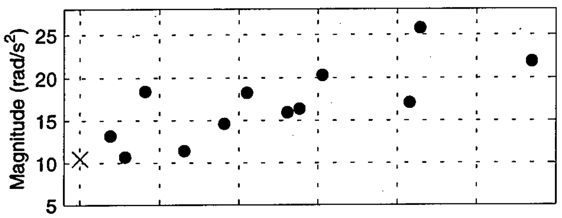
(b) Subject 3



(c) Subject 4



(d) Subject 5



(e) Average

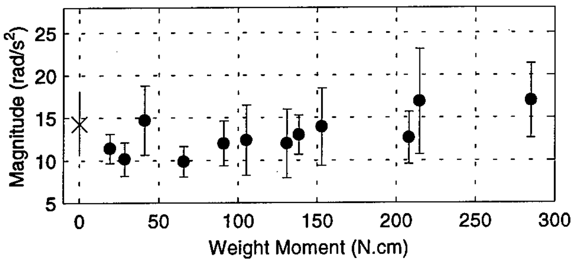


Figure 7. Magnitude of head pitch acceleration at first resonant frequency for subjects 2-5 (a-d). The axial magnitude was averaged among the four subjects as a function of weight moment (e). The symbol • represents the loaded cases and × represents the unloaded case. Error bars are ± 1 SD.

5. DISCUSSION AND CONCLUSIONS

Platform vibration in the axial (vertical) direction is transmitted through the seat to the musculoskeletal system of the subject causing involuntary head motion. Combined with the loading of HSDs, this head motion may fatigue the pilot and degrade performance. For all subjects, RMS magnitude responses of the head axial, AP, and pitch accelerations to ramp-up swept sine were similar to the ramp–down portion of the swept sine. In addition, the magnitude of the platform acceleration remained fairly constant throughout all 12 sessions. Note that head pitch acceleration was more sensitive to helmet loading than AP or axial acceleration. Figure 3 demonstrates this response for subject 3. Other subjects exhibited similar responses.

Acceleration magnitude changed consistently with respect to the input vibration among all helmets and for all subjects. Figure 4 is an illustration of this typical response from subject 3. In general, the resonant frequency of the head accelerations remained unchanged. Two resonant frequencies can be clearly identified from the head axial acceleration response. The first resonant frequency ranged between 3.5-4.5 Hz, and the second ranged between 7-8 Hz. These findings were in agreement with those of Butler's study involving male subjects [1].

Figure 5 indicates that head axial acceleration (peak at first resonance) tends to increase as the helmet weight moment is elevated. This relationship was obvious for subject 5. This trend does not agree with Butler [1], who concluded that head axial acceleration at the AOC for the male subjects did not change significantly due to helmet CM and mass. However, it is possible that axial acceleration for female subjects may be similar to that of male subjects after the testing of 12 subjects has been completed. Head axial accelerations for all female subjects ranged between 3-5 m/s^2, lower than the range of approximately 6-7 m/s^2 for the male subjects [1]. This gender distinction was true for all helmet configurations as well as for the unloaded case.

Butler [1] also showed that head AP acceleration for male subjects was insensitive to helmet loading. Similarly, for the female subjects, there was little change in the magnitude of head AP acceleration due to helmet weight moment (Figure 6). In addition, the female AP acceleration ranged between 0.5-1.5 m/s^2, similar to the accelerations seen in male subjects.

This study suggests that the average head pitch acceleration increased when the weight moment was elevated above 65 N-cm (Figure 7). This is in a general agreement with Butler's findings for male subjects where significant differences were found between helmets with weight moments above and below 83 N-cm [1]. Pitch acceleration levels for the females were similar to those of the males for helmets below 130 N-cm and lower for helmets above 130 N-cm. Only subject 5 had pitch acceleration levels that were similar to those of the male subjects.

The preliminary results reported in this paper suggest that head pitch acceleration for the female subjects is the most sensitive response to HSDs, compared with AP and axial accelerations. In addition, the gender differences in head motion reported in this paper may be attributed to head anthropometric differences between men and women.

Finally, the standard deviation of the female head accelerations was found to be similar to that of male subjects, suggesting that significant differences due to weight moment may be found after the testing of 12 subjects has been completed. Until then, no firm conclusions can be drawn.

In conclusion, we expect that this study will establish defensible HSD operational guidelines that provide equal protection for female aviators as they do for their male colleagues without hindering mission performance.

6. ACKNOWLEDGMENTS

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Past, Present and Future Night Vision Goggles in U.S. Army Aviation

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SUMMARY

The Department of the Army (U.S.) decided to increase night operational effectiveness with night vision devices (NVDs) for use in aviation in 1973. The first fielded NVDs for Army aviation were developed for ground troops and were known as the full faceplate AN/PVS-5 night vision goggle (NVG). In the 25 years that have followed, a number of engineering advancements have greatly improved the performance and mechanical packaging of these devices. For approximately the last 10 years, pilots have been using 3rd generation image intensifier (I^2) technology, which is known as the Aviator's Night Vision Imaging System (ANVIS). Although the basic principle of light amplification with a microchannel plate has not changed, the performance has and is due to the optimization of the components and the electronic designs. The latest NVD developments include wider fields of view (FOVs), increased resolution, reduced halos around lights, improved signal to noise ratios and low light performance. A prototype color vision I^2 device has also been demonstrated. This paper updates and condenses previous information on U.S. NVG history (Ref 1).

1. INTRODUCTION

During the Vietnam conflict, the Viet Cong used the night to their advantage to move supplies and launch attacks. In the daytime, U.S. helicopters could avoid small arms fire by flying above 3000 feet in route to the landing zones. With the introduction of more advanced air defense systems such as shoulder fired air defense missiles and radar controlled guns, it was apparent that helicopters could only operate near the enemy at very low level altitudes or below the trees [nap-of-the-earth (NOE)] to mask their presence. With unaided vision at night, NOE would be impossible, even under high moon illumination. Army aviation could only operate at night by flying at safe altitudes and using flares to illuminate a suspected target area, which resulted in numerous incidents of controlled flight into the ground. Passive generation (GEN I) night scopes (AN/PVS-2) were developed during this period that converted light into electrons and amplified the electrons with high voltage using a series of cascade stages that accelerated the electrons onto a phosphor screen (Ref 2). However, the scope weighed about 6 lbs and was used primarily as a rifle scope. By using a microchannel plate, electron amplification could occur with sufficient weight reduction to be fitted into a 2 pound binocular goggle. The microchannel technology was referred to as GEN II. The first fielded GEN II goggle was designated the AN/PVS-5* (Ref 3). *This nomenclature is an abbreviation of the following: the "AN" stood for Army or Navy application, "P" meant portable, "V" signified visual, and "S" indicated detecting or range bearing. With this infantry developed device, Army aviation found a means to begin night flight to support ground operations.

2. AN/PVS-5 NIGHT VISION GOGGLE

In 1975, Fort Rucker received four pair of AN/PVS-5 goggles to start the NVG program using standardization instructor pilots. In the beginning, flights were primarily limited to traffic pattern work. Student pilots were given 4.5 hours of NVG orientation until 1983, when the time was increased to 10 hours for NVG qualification including NOE and confined area training (Ref 4). The present flight time for NVG qualification was gradually increased to approximately 20 hours.

The basic principle of GEN II image intensification starts with the scene being focused with an objective lens on a photosensitive material, known as the photocathode. The photocathode surface emits electrons proportional to the amount of light striking it from each point in the scene. The emitted electrons are then accelerated from the photocathode into a microchannel fiber optic plate using high voltage that releases additional electrons as the electrons contact the walls of the microchannel plate. The microchannel plates are approximately 1 millimeter thick with the diameter of each channel measuring approximately 10 microns. As the electrons are accelerated from the microchannel plate, they then strike a phosphor screen. The light emerging from the phosphor screen is proportional to the number and velocity of the electrons striking it at each point. The image is upside down, but is inverted using a coherent fiber optic bundle that is rotated 180 degrees to erect the image. The observer views the intensified image formed on the fiber optic inverter through an eyepiece. See Figure 1.

Several models of the basic AN/PVS-5 NVG were fielded: the basic AN/PVS-5 and three modified versions, the AN/PVS-5A (Figure 2), AN/PVS-5B, and AN/PVS-5C. While all of the models differ in one or more ways, they all use the 2nd generation tubes. The AN/PVS-5B and -5C had f/1.2 objective lenses, as compared to the f/1.4 for the AN/PVS-5A; this allowed 50 percent more light to enter

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the I^2 tubes. Another 2nd generation goggle AN/PVS-5 type procured by special operations in limited quantities was called the Litton model 909. The gain and automatic brightness control levels in the tubes were set at higher values.

In the early 1980s, the U.S. Army Aeromedical Research Laboratory (USAARL) and NVG instructor pilots at Fort Rucker, AL also evaluated two NATO developed NVGs. The German second generation NVG used a friction lock swivel mount that allowed excellent look around unaided vision and accurate alignment of the NVG eyepieces with the user's eyes or a flip-up capability. The AA batteries were mounted on the rear of the helmet for counterbalance, and a white lip light was mounted on the helmet microphone. The first NVG model with see-through vision was called "Cat's Eyes" and was manufactured in 1983 by Marconi of U.K.(Ref 5). For helicopter flight, we did not find see-through vision as a benefit. When artificial lights were visible with both unaided see-through and aided intensified vision, they did not align exactly, creating confusion to the pilot. Other undesirable characteristics noted were the slightly smaller field of view, less low light resolution, and excessive phosphor persistence. Later advanced versions of the "Cat's Eyes" with generation three tubes were adopted by the U.S. Air Force and Navy for fixed wing fighter aircraft.

In general, the various NVG models with power supply weighed approximately 2.0 pounds (0.9 kilogram). The AN/PVS-5 were mounted to the helmet using Velcro straps and quick release straps for the side straps. From 1974 to as late as 1990, the AN/PVS-5 series with 2nd generation I^2 tubes were the primary NVGs used by U.S. Army aviators.

Since the AN/PVS-5 are I^2 devices, the amount of available light was extremely important. For the sensitivity of 2nd generation tubes, the moon is the major natural source of this light. However, aircraft were fitted with a visual attenuating, infrared (IR) transmissive filtered searchlight, called a "pink light" or invisible headlights, which allowed flight capability in the absence of lunar illumination. For training purposes, the "pink light" was mandatory for U.S. Army AN/PVS-5 flight with the moon less than an altitude of 30 degrees above the horizon and a fraction of illumination of less than 23 percent. The IR light is still required to be on the aircraft even with ANVIS, but its use is optional or in accordance with unit standard operating procedures.

The original full face AN/PVS-5 design that was adopted for aviation was very limited for combat use (Ref 6). The pilots could not read maps and had to refocus one objective lens to see the flight instruments. With only the aided 40 degrees FOV, the probability of a collision with other aircraft in a high density training area operating at similar altitudes was obviously increased over unaided daytime visual flight. The first NVG midair collision occurred in December 1981 during an NVG training mission at Fort Rucker, AL. From the accident investigation, USAARL was asked to reevaluate the bifocal AN/PVS-5 to determine if the pilots would have more outside-the- cockpit viewing time. Although the bifocal NVG, which provided instrument viewing without refocusing, was an improvement over the standard NVG, it was also obvious that the full faceplate NVG was undesirable for aviation. It was also discovered that the NVG instructor pilots were using counterweights when counterweights had not been approved. USAARL was also asked to evaluate the counterweight issues.

Although an NVG designed for Army rotary-wing operations was in development, and was initially planned for fielding in 1983, some technical and contractual problems occurred during operational testing that would delay the ANVIS for several more years. Army aviation needed a quick, cheap, reliable, and simple fix if NVG flight training was to continue to develop without unacceptable risks. Using faceplates that had been discarded due to damage in the bottom area, USAARL began modifying these faceplates by removing the lower half and moving the switch and battery compartment to the top of the faceplate. Working and consulting with NVG instructor pilots, the faceplate modifications were refined for reliability and simplicity. After an evaluation by 47 NVG instructor pilots and over 800 hours of flight, the modified faceplate was recommended for approval. The modifications to the AN/PVS-5 face plate, known as the "cut-a-ways" (Figure 3), provide increased look-to-the-side and look-under capability. The detailed procedure for performing the modification was developed and made available as early as 1982 (Refs 7&8). The modified version was accepted by the Army, Air Force, and Navy, and became the standard NVG configuration in 1983 (Ref 9). Several other face plates and mounting configurations were also used with GEN II image intensifiers.

3. AN/AVS-6 ANVIS

Combat equipment developers recognized that the adoption of the first infantry NVGs for Army aviation was only temporary until a more advanced system could be designed and manufactured. Unfortunately, aviators had to use the older Gen II technology for aviation for over 10 years. Although the first operational tests were in 1982, it was not until 1989 that 3rd generation tubes began to make their appearance in significant numbers.

ANVIS (Figure 4) is a binocular, 3rd generation, I^2 night imaging system. The image intensifier tubes are sensitive over a spectral range of approximately 550-950 nanometers (nm). This spectral range is slightly altered by using a dielectric coating (minus blue filter) incorporated in the objective lens. This coating for the Army is labeled a Class A minus blue filter and rejects energy below 625 nm. The minus blue filter is designed to provide compatibility with blue-green cockpit lighting. For the Navy and Air Force, a Class B minus blue filter is used which blocks wavelengths below 665 nm. ANVIS provides a circular 40-degree FOV and provides an average display luminance from a uniform background at the eye of between 0.7 and 2.2 footlamberts (fL). In comparison to AN/PVS-5, ANVIS has increased sensitivity, improved resolution, and a greater sensitivity in the near infrared (Ref 8). Spectral sensitivities of 2nd and 3rd generation 18-mm tubes are compared in Figure 5, along with the normalized night sky radiance.

ANVIS optical and performance characteristics (Omnibus I and II, which are specifications for procurement contracts) include: a focus range of 28 cm (11 inches) to infinity, unity (1x) magnification, 27-mm effective focal length objective (f/1.2), 27-mm effective focal length eyepiece lens, >0.82 cycles/milliradian (cy/mr) or 20/42 Snellen resolution, 2000x brightness gain (minimum), -6 to +2 diopter adjustment, and 52-72 mm interpupillary distance adjustment. The ANVIS housing can be flipped up or down, and has a 10 gravitational force breakaway feature. A tilt adjustment of approximately 8 degrees is provided. There is a minimum vertical and fore/aft adjustment range of 16 mm. They operate for approximately 20 hours from one 3-volt lithium or two alkaline "AA" batteries. A dual battery pack is mounted on the rear of the helmet to provided electrical redundancy and improve the location of the head supported center of mass (CM). The green phosphor initially was P20, but was changed to P22 for Environmental Protection Agency considerations.

The Omnibus III procurement provided a minimum of 3000x brightness gain, eyepieces with 25-mm eye clearance, increased fore-aft range to 27 mm, and individual interpupillary distance (IPD) adjustments. The phosphor was P22. Resolution under optimum conditions is approximately 0.98 cy/mr or 20/35. Omnibus IV image intensifiers use a faster greenish-yellow phosphor (P43) with reported resolution of 1.38 cy/mr or 20/25 and system light amplification gain over 5000x. To improve the user's ability to accurately focus the objective lenses with the increased resolution from the Omnibus III and IV image intensifier tubes, a fine focus objective lens was incorporated in the ITT, model F4949 ANVIS. Instead of a half turn to change focus of the objective lens from infinity to 28 cm, it requires two turns to change the focus from infinity to 1 meter. The F4949 ANVIS housing with the Omnibus IV tubes is referred to as the ANVIS-9 (See Figure 6).

The first major contract for ANVIS, awarded in 1982 (Omnibus I), called for a delivery of 1366 units. By the end of 1994 with Omnibus II, over 16,000 ANVIS had been delivered or were under contract. As of 1998, with Omnibus IIIs and IVs, the total number was approximately 18,000. (Ref 10)

The look-under capability with ANVIS, with compatible blue-green instrument lights, allowed aviators to view cockpit displays without refocusing the goggles. In the early 1980s, several prototype miniature Head-Up Displays (HUDs) for ANVIS were investigated (Refs 11&12). The purpose of the HUD was to provide flight information during critical phases of flight such as NOE and low level flight. After several design considerations, the ANVIS/HUD, AN/AVS-7, was selected, with initial fielding in 1995. The display unit of the ANVIS HUD attaches to either the right or left tube housing and optically couples selectable flight information with the intensified image through the objective lens of the ANVIS. The pilot and co/pilot can individually select eight different symbology modes of which four can be individually programed. The modes and brightness can be selected with a four-way switch on the engine power control (collective/thrust stick/throttle) or on the control box. Approximately 12 different types of information are available such as altitude (barometric and radar), velocity (ground and airspeed), heading, attitude indicator, way point direction and distance, etc. The master caution and warning information are displayed with all eight modes. Presently the ANVIS HUD is fielded on two Army aircraft (UH-60 and CH-47).

4. AN/PVS-7 and AN/PVS-14 NIGHT VISION GOGGLES

Two additional head mounted U.S. infantry versions of NVG will be described because they have or will be evaluated in the aviation environment. The first is the AN/PVS-7 series NVG which has replaced the AN/PVS-5 for ground use. The AN/PVS-7 is a biocular (single 3rd generation I^2 tube providing the same view to each eye), 40-degree FOV design (Figure 7). The AN/PVS-7 has not been used for helicopter flight except to evaluate biocular performance. Future helicopter visual flight systems are based on a biocular design such as the pilotage system for the Comanche helicopter, where a single nose mounted, head coupled, thermal sensor image is seen by both eyes.

The replacement for the biocular AN/PVS-7 is the AN/PVS-14 Monocular Night Vision Device (MNVD), which uses a single advanced 3rd generation tube to provide aided monocular vision for one eye, leaving the other eye dark adapted or adjusted to the ambient illumination (Figure 8). The addition of a manual gain control for the AN/PVS-14 and a removable pen hole lens cap permits adjustments for ambient light over very large ambient urban night lighting conditions (>5 log units). The AN/PVS-14 has improved resolution to 1.3 cycles per milliradian (cy/mr) and adjustable gain from 25 to >7000. Interestingly, when the intensified image is adjusted with the manual gain and focused at the same distance as the

Table1: Evolution of NVG Resolution and Gain

NVG	Resolution (Snellen)	Resolution (lp/mm)	System Gain (typical)
AN/PVS-5 (60° FOV)	20/70	28	800
AN/PVS-5(40° FOV)	20/50	28	800
AN/AVS-6 (Omnibus I & II)	20/40	36	2000
AN/AVS-6 (Omnibus III)	20/32	45	3000
AN/AVS-6 (Omnibus IV)	20/25	64	5000
AN/PVS-14 (Omnibus IV)	20/25	64	7000

unaided eye, the unaided and aided images fuse showing stereo vision on the circle targets in the Armed Forces Vision Tester and no perceptual retinal rivalry. The observer is able to recognize the colors of luminated objects or sources. This MNVD has potential for pilotage and observation from both military and civilian aircraft.

Table 1 summarizes the evolution of the maximum resolution and typical gain of the NVGs. Resolution is expressed as both Snellen acuity and line pairs per millimeter (lp/mm). Gain is defined as the magnification between the luminance output from the eyepieces of the NVGs to the luminance input for a 2856 degree Kelvin incandescent light source, which replicates the spectral radiance and color temperature of the night sky.

5. PSYCHOPHYSICAL PERFORMANCE

When I^2 devices are added to the aviator's head to allow night and low illumination operation, night is not "turned into day." The visual input provided by these systems does not equal that experienced using the unaided eye during periods of daylight illumination. When compared to unaided daylight flight, many visual parameters, e.g., acuity, FOV, depth perception, color vision, etc., are understandably compromised (Refs 13-15). However, the latest developments in image intensification technology are improving these functions.

5.1 Resolution and visual acuity

Resolution, referred to in optics as resolving power, is defined as the ability of an optical system to reproduce the points, lines and surfaces in an object as separate entities in the image. The resolution usually is expressed in either linear or angular units as the separation between two object points which can be viewed as separate images. The system resolutions of I^2 devices usually are expressed in angular units such as Snellen resolution or "cycles per milliradian (cy/mr)." For I^2 tubes, a linear unit of "line pairs per millimeter (lp/mm)" is used to separate the optical characteristics of the objective and eyepiece lenses from the resolution of the intensifier tube. At moonlight illumination levels, AN/PVS-5 resolution is specified at 0.72 cy/mr (20/48); and ANVIS (Omnibus I and II) resolution is 0.86 cy/mr (20/40). At starlight levels, AN/PVS-5 resolution decreases to 0.40 cy/mr, and ANVIS resolution decreases to 0.55 cy/mr.

Optimal I^2 resolution is obtained under high moon light level conditions with high contrast targets. The resolving power of an I^2 device decreases with decreasing light level because of the proportional decrease in luminance output below the automatic brightness control level, and the noise in the intensified image increases. Although there may be a measurable resolution at very low light levels, the AN/PVS-5 loses its effectiveness at about starlight, as visual acuity approaches 20/100, and the original ANVIS loses its operational effectiveness at overcast starlight.

In order for aviators to take full advantage of the I^2 devices' resolution capability, the goggle should be focused for both the objective and eyepiece lenses. With the very fast ANVIS objective lens, the depth of focus is very small, where one diopter of objective lens blur equates to approximately 20/700 visual resolution. Diopters equal the reciprocal of the focal distance in meter units. Therefore, the minimum recommended distance for adjusting the ANVIS objective lenses for infinity is 50 meters (Ref 16). Each of the eyepieces for ANVIS are independently adjustable over a range of +2 to -6 diopters. This extensive diopter adjustment range was based on the older AN/PVS-5 NVGs, which were not compatible with prescription spectacles. The adjustable eyepiece focus provides the potential for optimum resolution for the variability of the refractive states of the users under low light through electro-optical devices (Ref 17).

A study (Ref 18) conducted by Kotulak and Rash, (1992), investigated effects of night sky condition, target contrast, and generation of I^2 device on visual acuity. It was found that the difference in visual acuity between the 2nd and 3rd generation I^2 devices widens under two conditions: 1) when target contrast is constant, but night sky irradiance that for a given I^2 generation, visual acuity falls off more rapidly for a low contrast target than for a high contrast target as night sky irradiance deceases.

A recent (1996) study (Ref 19) looking at visual acuity in I^2 devices found that contrast attenuation (reduction) associated with I^2 devices is a major factor in limiting visual acuity of such devices. This contrast attenuation is determined by the modulation transfer functions of the optical and electrical components of the I^2 devices and the presence of noise. In addition, output luminance is very likely a factor, since several studies have documented acuity loss at low levels of sky illumination. This report contains equations to calculate contrast and luminance effects with NVGs.

5.2 Field of view

For a 1x magnification NVG, the FOV is primarily determined by the focal length of the objective lens and eyepiece, and the diameter of the sensor and display. Unfortunately, increasing FOV results in a proportional loss of resolution above eye limiting values. A study (Ref 20) investigated visual acuity versus FOV and ambient light level for a single I^2 tube. Snellen visual acuity was measured for three FOVs (40, 47, and 52 degrees circular) and five different light levels (output luminances). In general, visual acuity decreases as ambient illumination decreases below about approximately 1/4 moon, with an optical increase in FOV. When a 1975 study (Ref 21) asked seven aviators to compare two AN/PVS-5 night vision goggles, one with a 40-degree and another with a 60-degree FOV, five of the seven rated the 40-degree goggle as providing the "sharper" imagery. The conclusion was that the aviators in this study preferred higher resolution over increased FOV at this stage of image intensifier development. Since Army NVG pilots have become accustomed to 40 degree FOV, when shown the 60 degree FOV with advanced image intensifier tubes, they still tended to prefer the improved resolution with the same tubes at 40 degrees FOV.

To increase the horizontal FOV without decreasing resolution, partial overlapping FOVs have been proposed for both NVGs and helmet mounted displays, i.e., the Comanche helicopter. In the mid 1980s, by converging the right and left channels of a AN/PVS-5, a partial overlapping FOV NVG was demonstrated, but was not fielded (Ref 12).

Although we usually only refer to the FOV of the display for NVGs, the unaided FOV outside the NVG can also be used for detection. Measurements of the peripheral retinal sensitivity with and without a monocular ANVIS at high and low night ambient illumination at six different locations showed that the unaided eye remained dark adapted to the ambient light level. Detection of small white, green, and red lights with peripheral vision outside the NVG FOV were moderately depressed, with the effects more for the white targets and least for the red targets (Ref 22).

5.3 Stereopsis and depth perception

Stereopsis is the perception of relative differences in the distances of objects from the viewer resulting from the simultaneous vision with both eyes and the separation distance between the eyes or viewing perspective. Normal stereopsis is most functional within distances of approximately 10 meters. Depth perception is the ability to judge one object's position with respect to another object based on both monocular and binocular cues. Stereo vision with AN/PVS-5 and ANVIS is theoretically possible since the two I^2 tubes provide two images viewed at the normal eye separation distance (Ref 14).

The phenomena of stereopsis and depth perception were explored first for the AN/PVS-5 in a 1976 study (Ref 23). Both laboratory (using a modified Howard-Dolman apparatus) and field experiments were conducted. Four viewing conditions were used: unaided monocular, unaided binocular, monocular (single) I^2 tube, and binocular NVG. This study concluded that stereopsis through night vision goggles, regardless of the model or viewing conditions, is essentially eliminated and equivalent to the threshold obtained with unaided monocular viewing. However, a more recent study in 1990 (Ref 24) using ANVIS produced conflicting results. Assessing stereopsis with ANVIS and unaided vision under varying light levels, this study concluded that stereo vision is present with I^2 devices and that they provide depth perception which was better than with unaided vision when the ambient levels are lower than twilight. In another report (Ref 25), after using NVGs, some pilots had reported decreased stereopsis. In a contact lens study, using the original day filters with ANVIS and the Armed Forces Vision Tester (AFVT), most of the pilots were able to pass the stereopsis test with the circle targets used for flight physicals (Ref 26).

Thirteen Army aviators were used to evaluate their ability to estimate (absolute) and maintain (relative) height above terrain using: 1) unrestricted day vision, 2) 40 degree restricted field of view with day vision, 3) ANVIS monocular at night time, 4) ANVIS binocular at night time, and 5) Forward Looking Infrared (FLIR) thermal sensor coupled to a monocular helmet mounted display at night time (Ref 27). The results showed that subjects performed poorly when asked to provide absolute altitude estimates under any condition, but were more reliable in estimating changes in altitude. The FLIR altitude deviations were consistently worse than the other viewing conditions.

In summary, stereopsis with night imaging devices does not seem to provide any significant additional depth perception information over the strong monocular cues such as motion parallax for helicopter flight. The successful use of the monocular IHADSS in the AH-64 Apache helicopter implies that sufficient depth estimations for pilotage can be obtained with normal flight training.

6. HEAD SUPPORTED WEIGHT

A review of helicopter crash injuries indicates a lack of evidence supporting significant neck injury for Army aviators wearing a 1.5-1.8 kg helmet. In some crashes, heavier helmets of 2.9 kg (including night vision components) have been worn, but the extra 1.1 to 1.4 kg mass of night vision goggles and counterbalance weights have broken free from the helmet and relieved the neck of this added loading. A survey of 37 NVG instructor pilots found an average head supported weight of 2.6 kg with a range from 2.1 to 3.1 kg with helmet, ANVIS, battery packs, counterweights, and auxiliary equipment. The average counterweight with ANVIS was 0.36 kg, with a range from 0.25 to 0.62 kg. An epidemiological survey of helicopter accidents from 1985 through 1994 showed no significant increase in neck injuries with the use of NVGs, but found an increase in head injuries with the older AN/PVS-5 NVGs, which were primarily mounted to the helmet with surgical tube and straps (Ref 28).

7. CURRENT ISSUES

7.1 Phosphor type.

The display on the eye end of the AN/PVS-5 and ANVIS includes a phosphor screen. The phosphors selected for NVGs were based on luminance efficiency, eye sensitivity, persistence, and signal to noise concerns. The AN/PVS-5 initially used the P20 phosphor. P20 is yellow-green, relatively narrow band (100 nm), and has a peak of 530 nm. Due to a noise problem (related to the low cathode sensitivity of the 2nd generation tubes), the P20 was replaced with an RCA F2126-type 1052 phosphor. This replacement was similar to the P20 in that it was yellow-green and peaked close to 530 nm. This phosphor also had a slower persistence than the P20. ANVIS has used P20 and P22 phosphors (both yellow-green in color with peaks near 530 nm).

Intensifier tubes purchased after 1995 (Omnibus IV) use P43 phosphor. P43 also is yellow-green in color but the primary lobe is extremely narrow band (5 nm) and peaks at 543 nm. The persistence (10%) of P43 is 1.2 milliseconds, making it a medium-short persistence phosphor. P43 is the phosphor used in the miniature cathode ray tubes in AH-64 Apache's Integrated Helmet and Display Sighting System (IHADSS). A 1996 laboratory (Ref 29) and flight evaluation study found little difference in performance of the P43 over the P22 except that pilots noted an absence of the comet-like tails following small lights for the P43 with head movements. Another reason for selecting the narrow band P43 was the possibility of simplifying the eyepiece design and reducing weight in correcting chromatic aberration.

7.2 Omnibus Evaluations.

As the ANVIS improved with each new contract in high and low light resolution, the issue of using the older Omnibus II with the latest Omnibus IV ANVIS in the same cockpit or flight formation was raised. It had been previously determined during the initial fielding of ANVIS that the GEN II AN/PVS-5 amplified the blue-green light more than the ANVIS. The decision had been made to not mix the ANVIS and the AN/PVS-5 NVGs in the same cockpit, both from the significant difference in cockpit lighting compatibility and overall performance.

Both the Navy and Army evaluated the use of Omnibus II and IV ANVIS in the same cockpit, reaching a different conclusion. The Navy, using nine NVG pilots, concluded that the Omnibus II and IV *could not* be safely mixed in the same cockpit or formation (three out of nine felt that mixing was unsafe) (Ref 30). The Project Manager, Night Vision/Reconnaissance, Surveillance, and Target Acquistion requested the Aviation Training Brigade at Fort Rucker, AL to also evaluated mixing Omnibus II and IV ANVIS. Using 24 NVG instructor pilots at Fort Rucker, the Army concluded (22 out of 24 felt mixing was safe) that the two different Omnibus intensifiers *could* be mixed in the same cockpit without affecting safety. All pilots comparing the older and latest ANVIS have noted the significant improvements in low and high light resolution with the Omni IV tubes, but the Army pilots felt that flying any more aggressively than permitted with Omnibus II would be a safety hazard.

7.3 Hyperstereopsis.

Stereopsis is a binocular depth perception cue, requiring two slightly laterally displaced inputs for the eyes and sensors. Thresholds for normal stereopsis have been reported from 1.6 to 24 seconds of arc, which is the difference in the eye convergence angles between two objects. For aviators, the passing value for stereopsis on flight physicals with the Armed Forces Vision Tester is 24 arc seconds.

The Integrated Night Vision Imaging System (INVIS) program attempted to design a night vision image intensifier system with lower weight and improved center of mass for fixed wing aircraft. The objective lenses and intensifier tubes were placed on the sides of the helmet with a separation approximately 4 times wider than the average separation between the eyes. This wider than normal sensor separation induced a phenomenon called "hyperstereopsis," which is characterized by intermediate and near objects appearing closer than normal. As one viewed intermediate objects, distant objects may appear even further away. In a hallway, the floor, ceiling and side walls appear to slope towards the view-point of the observer. Flights in a modified AH-1S at Fort Belvoir, VA, showed that hyperstereo and sensor placement on the sides of the helmet were undesirable during terrain flight, and especially during the landing. The vertical supports in the canopy blocked the objective lenses with head movements, and outside vision would noticeably dim under star-light conditions when one objective lens was blocked. The test pilots rated the hyperstereo system unsafe and terminated the study, except for demonstration rides (Ref 31). The Germans evaluated the GEC candidate for the INVIS program in a helicopter, and we understand they also found similar observations and concluded that hyperstereo was undesirable.

A hyperstereo study was conducted at Fort Rucker using an "eagle eye" NVG with a 2 to 1 increase in IPD, the Honeywell INVIS with 4 to 1 increase in separation, a standard ANVIS, and the FLIR, with the subject in the front seat in an AH-64 Apache (Ref 32). The results showed no difference in flight performance among the different night imaging combinations. However, the pilots' subjective responses indicated they preferred the ANVIS over the two hyperstereo systems. They also stated that they did not like the I^2 switched to FLIR during the landing phase, primarily because of the poorer resolution of the FLIR compared to the I^2 devices. The sensor switching was not controlled by the evaluating pilot on the controls, but by the safety pilot.

7.4 Luminance imbalance between right and left NVG images.

One of the causal factors listed in a 1996 mid-air collision between two Australian Army helicopters in formation was a speculation of possible luminance and contrast imbalance between the right and left channels of the NVGs. A criteria of 10 percent difference was considered significant (Ref 33). Using field and laboratory measurements, the luminance eyepiece outputs were measured for 20 pair of ANVIS considered acceptable by the NVG pilots at a U.S. Army helicopter training field. The measurements were taken above and below the automatic brightness control (ABC) value by varying the input into the NVGs using an NVG test set. The results showed that 80 percent of the NVGs surveyed did not meet the suggested 10 percent luminance imbalance criteria (Ref 34). Other visual literature suggests that up to 30 percent difference between the eyes would be required before any significant changes in binocular visual performance could be measured.

7.5 Color multifunction displays and NVG compatibility.

Along with the designing of ANVIS, emphasis was given to the development of compatible cockpit lighting. Testing for ANVIS "compatibility" is performed in accordance with MIL-L-85762 (Ref 35). MIL-L-85762 (revised to MIL-L-85762A in 1987) is a tri-service specification adopted to establish performance, general configuration, and test and acceptance requirements for ANVIS compatible aircraft interior lighting (Ref 36).

Until recently, the light sources used in the NVG cockpits have been primarily filtered incandescent bulbs, light emitting diodes, or monochrome cathode ray tube (CRT) displays. The last few years have seen the emergence of a new class of displays called flat panel displays (FPDs). These new displays are based on a number of different technologies, i.e., liquid crystal (LC), electro luminescent (EL), light emitting diode (LED), plasma, field emission, etc., and may include full color capabilities.

A cockpit complying with the current compatibility specification for ANVIS using a 625 nm "minus blue" filter precludes the use of full color displays or any color display using red. However, the issue of "what is user acceptable with ANVIS" as opposed to "military standard compliant" with full or limited color displays in the helicopter cockpit has not been determined and is being evaluated (Ref 37).

8. THE FUTURE OF NVGs

NVGs have continually improved since the first AN/PVS-5. The methods used to improve the maximum I^2 performance was the optimization of the optics, the characteristics of the intensifier tubes, and determining the relationships between the combinations of these characteristics. Under the Improved Resolution Wafer Tubes Program, the various intensifier tube component parameters were varied in various combinations to maximize resolution and modulation transfer function (MTF) without reducing the signal to noise ratio. Some of the variables were microchannel dimensions, component spacing, phosphor size and types, and the various power supply voltages (Ref 38).

The first AN/PVS-5 NVGs used 18-mm 2nd generation intensifier tubes with a resolution specification of 25 line pairs/mm, a luminance gain from a standard 2856 degree Kelvin light source of 400, and typical life expectancy of less than 1000 hours. Recent 18-mm 3rd generation tubes have demonstrated resolutions greater than 70 line pairs/mm and gains of more than 5000, with life expectancy of up to 10,000 hours. Other developments include reduced electron spread (halos) around bright lights, faster phosphors, and improved signal to noise ratios.

The current Air Force priority in I^2 development is a wide field of view panoramic NVG for fighter aircraft that will fit under the visor and provide safe ejection without prior removal. Using a 30 horizontal (H) by 40 degrees vertical (V) central intensified image to both eyes and two 35 H by 40 V degree outside intensified panels, an FOV of approximately 40 by 100 degrees has been demonstrated in a prototype that weighed no more than the present ANVIS with resolution of .95 cy/mr (20/36) at 1/4 moon illumination. Unfortunately, the wide FOV is achieved with short eye reliefs that are not physically compatible with corrective spectacles and protective masks. Increasing the eye clearances will reduce the FOVs and/or increase system weight.

During the advanced image intensifier (AI^2) program, a 60-degree FOV NVG was produced with a built-in display for overlaying symbology. The resolution is approximately 0.86 cy/mr (20/40) and the weight is similar to the present ANVIS. However, this development has strong competition from the previously mentioned panoramic NVG and the latest Omnibus ANVIS.

Sensor fusion or selection between image intensifiers and thermal sensors for pilotage has been in development since 1991 (Ref 39). However, the cost, complexity, weight, reduced resolution of the image intensifier, limited electronic band width, and lack of an acceptable helmet mounted display have kept the program from progressing to a production system. The near term solution has been to use current NVGs and a nose mounted thermal sensor that is viewed on a head down panel mounted display.

Another NVG development is the ANVIS camera system that can be used for NVG documentation and training. A small charged-couple device (CCD) camera is optically coupled to one of the intensifier tubes in the ANVIS at the eyepiece (Figure 9). What the pilot sees can be recorded or transmitted as a video image. The FOV of the video is reduced to approximately 20 degrees to provide resolution approximately one-half that of the actual intensified 40 degree image.

Even with the performance from the latest image intensifier technology, the monochrome presentation may not provide sufficient contrast to distinguish from similar reflective objects. To demonstrate what a color NVD might look like, we used a black and white video CCD camera with spectral response from approximately 400 to 900 nanometers and two filters with different spectral transmissions. One filter transmitted only the visible (400 to 700 nm) and the other, the red and near infrared spectrum (650 to 1000). Capturing the same daytime scene with and without each filter in front of the objective lens, the three images were combined using a computer graphics program and the primary colors. This technique demonstrated the potential advantage of a color NVD before actual hardware procurement.

After the color vision NVD concept was described at a tri-service Navy NVG workshop in 1994, a color NVD demonstrator was built using off-the-shelf commercial components. This demonstrator showed advantages in detecting camouflage targets and distinguishing blood from other fluids. An improved colored NVG has been funded with the latest image intensifier with improved low light performance.

9. CONCLUSIONS

By the late 1980s, the combat developers had envisioned all future helicopter electro-optical vision systems would use turret mounted thermal (1-3 or 8-12 micron) sensors and image intensifiers with image fusion for night and adverse weather flight. The simpler helmet mounted image intensifiers we call ANVIS, would become obsolete. The number of U.S. manufacturers of quality image intensifier systems has gradually reduced with the decrease in government demand. However, the performance and potential from the latest NVG developments has provided a technology advantage over any other night flying system, and should continue into the 21st century.

Disclaimer

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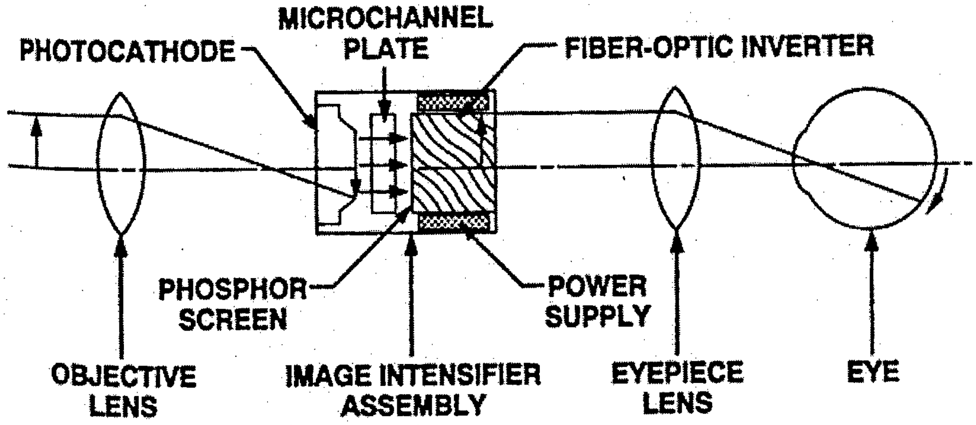

Figure 1. Diagram of the basic components of image intensification.

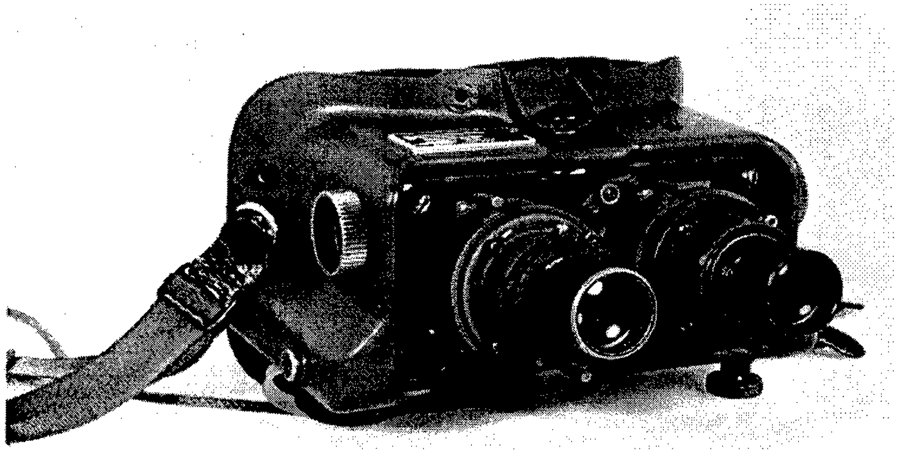

Figure 2. The AN/PVS-5A night vision goggle.

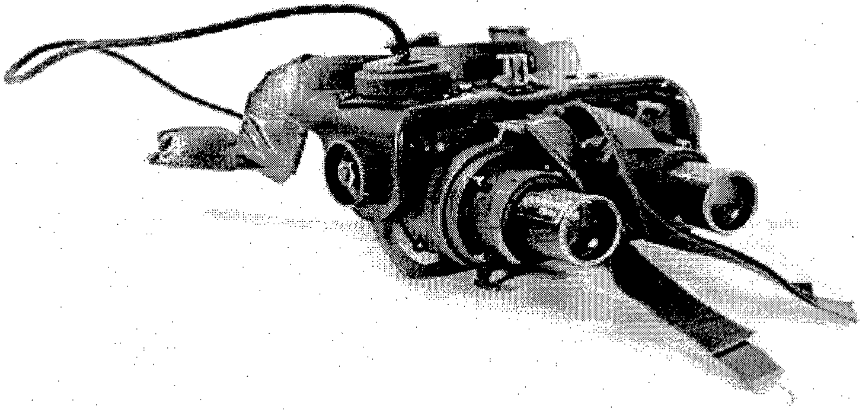

Figure 3. The prototype cut-a-way version of the AN/PVS-5.

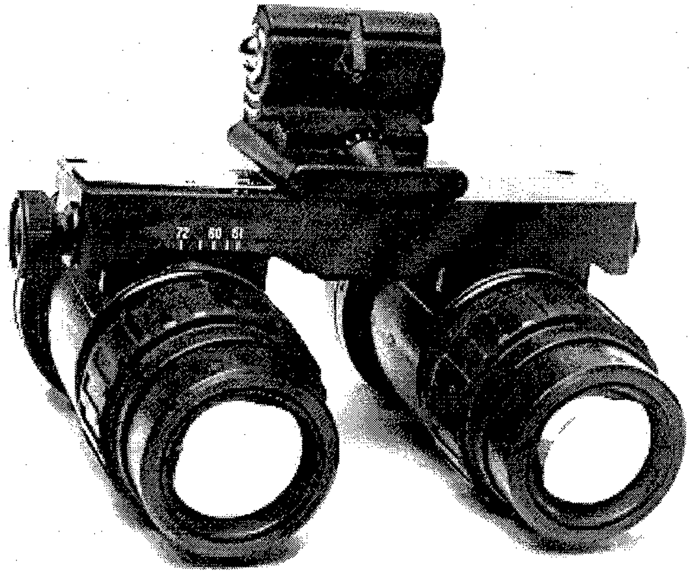

Figure 4. Aviator's Night Vision Imaging System (ANVIS) under OMNIBUS I & II.

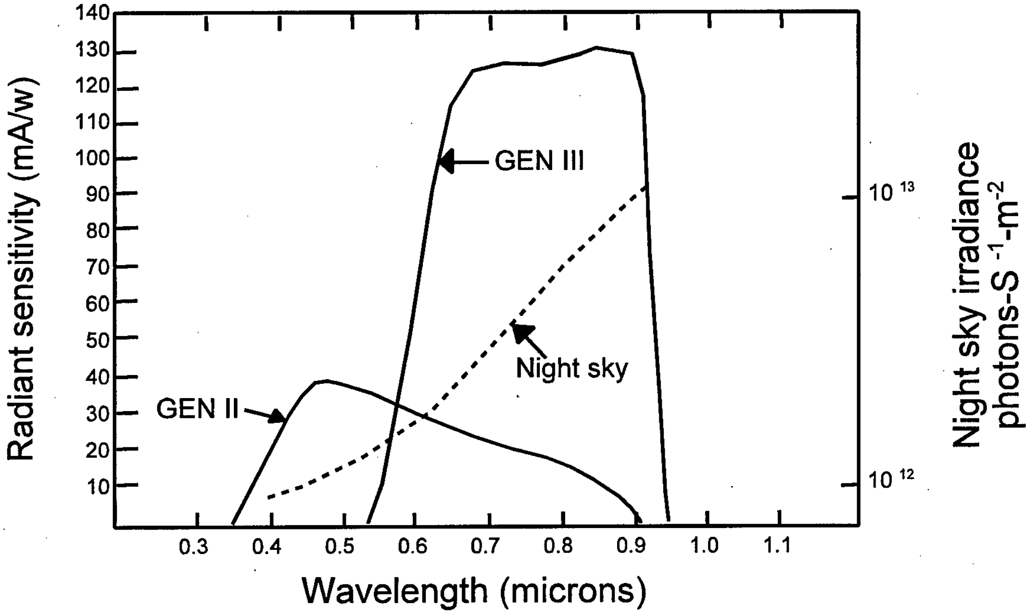

Figure 5. Comparison of 2nd and 3rd generation tube sensitivities in 1982.

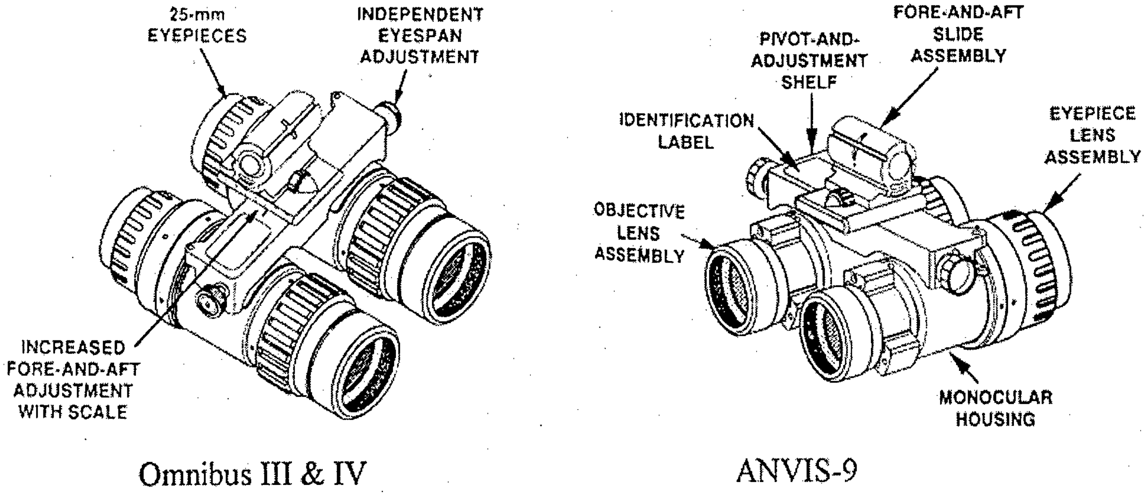

Figure 6. ANVIS under Omnibus III & IV, and ANVIS-9.

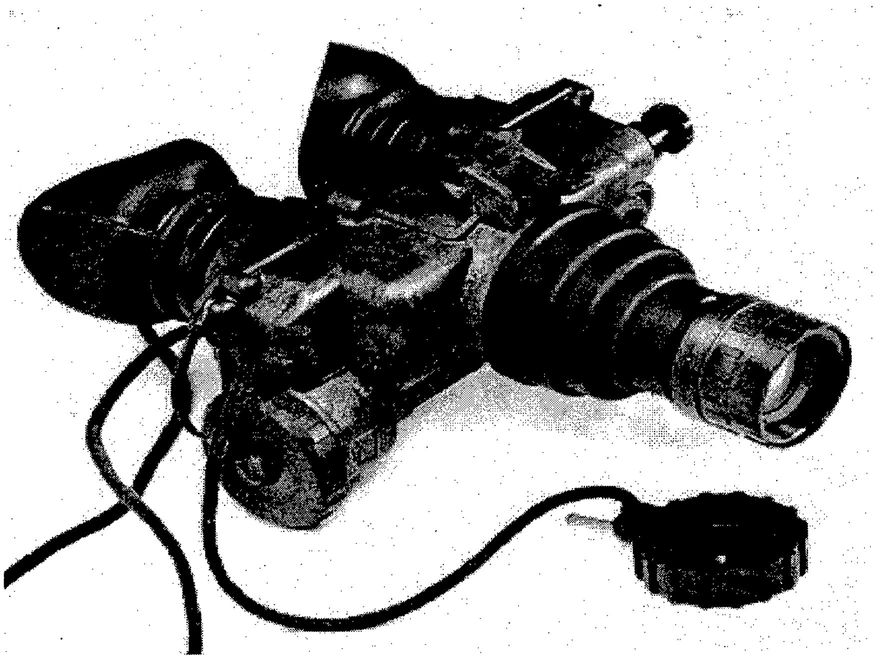

Figure 7. The AN/PVS-7 single tube biocular NVG for ground use.

Figure 8. The AN/PVS-14 Mponocular Night Vision Device (MNVD) for ground use.

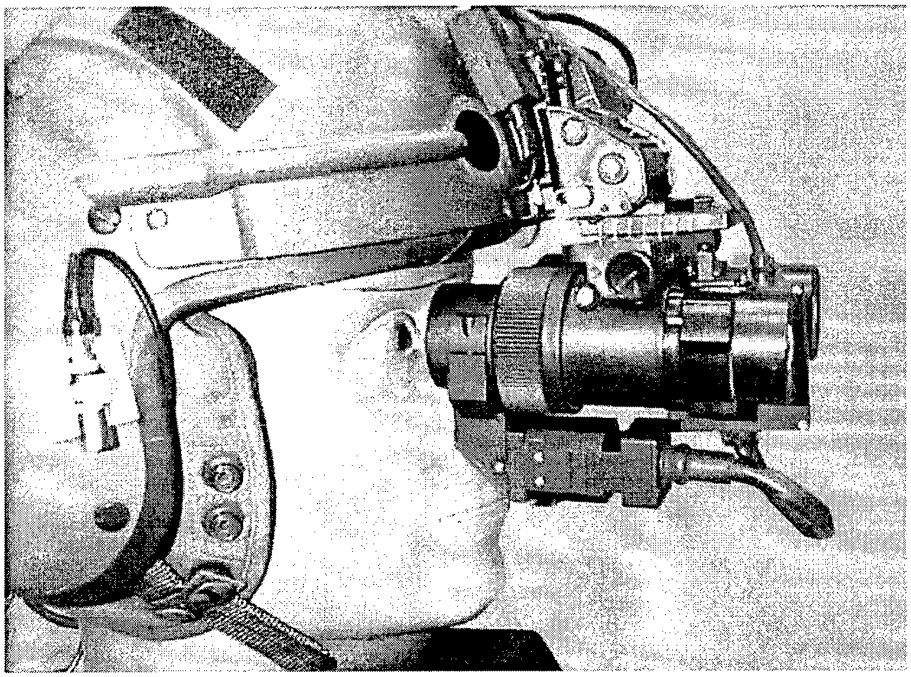

Figure 9. ANVIS CCD camera system

Double hearing protection and Speech Intelligibility - Room for Improvement

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Summary

Double hearing protection is used in many air forces around the world for protection in noisy aircraft environments, particularly in helicopters. The usual combination is foam ear plugs under headset or helmet muffs. Much of the research that spurred the introduction of foam earplugs indicated little change in speech intelligibility in persons with normal hearing. However, air crew often complain about having to maximise intercom volume for speech understanding, causing a situation with no reserve volume and bad sound quality. In recent years, further developments include so-called Hi-Fi plugs and custom made ear plugs which are claimed to improve speech communication. The aim of the present project was to investigate different types of ear plugs and their effect on speech intelligibility in helicopter noise.

Each of nine normal-hearing pilot subjects were placed in an environment of recorded helicopter noise from a BO-105 helicopter. Speech audiometry was performed under four different conditions: Headset only and three different ear plugs worn under the headset. Fitting of the ear plugs was performed by an ear, nose and throat specialist to ensure similar conditions. The sequence of test conditions was randomised and double-blind. In addition, a subjective rating scale was used.

Wearing foam ear plugs under the headset decreased speech intelligibility dramatically. The "HiFi" plug was somewhat better than foam plugs, and the custom made ear plug provided a speech intelligibility close to the headset-only situation. Subjective rating scores coincided with these findings.

In helicopter noise, custom made ear plugs may provide a much improved speech intelligibility over conventional foam ear plugs worn under the headset.

Introduction

The aviation environment frequently implies high noise levels (1). The use of hearing protection in aviation has a long history, and the methods by which noise levels are suppressed have constantly evolved. Recent developments in hearing protection for aviators include Active Noise Reduction (ANR) (2;3) and communication earplugs (4). Ear muffs have been use for large parts of aviation history, but have also been gradually improved. The best ear muffs today have much improved performance as hearing protectors than those of earlier years. The use of hearing protection in the aviation environment has two main objectives, namely to fascilitate a reasonable signal-to-noise ratio for communication on the one hand, and to protect against noise-induced hearing loss on the other.

In many aircraft, noise levels are so high that ear muffs alone cannot ensure full protection from noise-induced hearing loss. Many military aircraft belong to this group, along with several civilian helicopters. A large low-frequency component to the noise is an additional reason for using double hearing protection, since ear muffs are less effective in this frequency region.

In the Norwegian Air Force, many aircrew members use ear plugs, most commonly foam-type plugs. When these where introduced in the 1970's, it was thought that, given normal hearing, speech intelligibility would not be significantly affected by such foam plugs. This was based on research performed on test persons using ear plugs alone in noise without headsets(5-7). The rationale was that although sound levels in the ear are reduced, the signal-to-noise ratio remains the same. Practical use has however shown us that many of our aircrew experience reduced intelligibility when using plugs under ear muffs.

Other air forces have also experienced this problem (8). Possible solutions include Active Noise Reduction (ANR) or introducing the communications signal through the ear plug. However, both these techniques introduce additional technical, ergonomic and economic

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aspects which might complicate practical introduction in many cases.

In recent years, some new types of ear plugs have emerged on the market. The traditional foam plug provides a good overall sound attenuation, but more so in the high-frequency range than in the lower frequencies. Other plugs with acoustical filters have therefore been developed with a more even frequency response, these are sometimes referred to as "HiFi plugs". Custom made ear plugs with acoustic filters represent a further refinement, marketed as the best solution for musicians or other people in need of good sound quality while still providing noise protection.

The aim of this project was to measure the effects of different types of ear plugs on speech intelligibility when worn under ear muffs, and to investigate any room for improvement in this aspect.

Subjects and Methods

Subjects

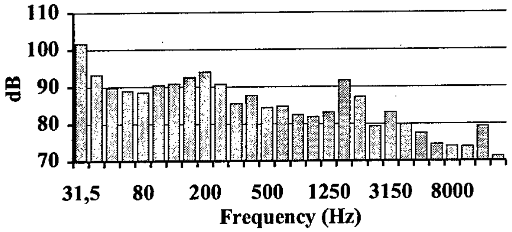
Nine male general aviation pilots with normal hearing were used as subjects for this project, age range 25-38 yrs. They all had normal hearing. Approval from the regional committee for medical research ethics was obtained.

None of the subjects had any history of chronic conditions affecting the ear, or present ear-related symptoms or diseases. Clinical otological examination was performed before each test, and was normal for all subjects.

Noise environment

Recorded helicopter noise from a BO-105 helicopter was used inside a sound-proof chamber. The BO-105 cockpit noise has a large part of the noise energy in the low-frequency region and is therefore suitable for this study. Fig. 1 shows a 1/3 octave spectrum of this noise as used in the laboratory. Noise levels were continuously computer monitored and logged throughout all experiments, using a Bruel & Kjær type 2135 sound level meter connected to a personal computer with type 7636 statistical noise analysis software.

Figure 1. BO-105 Cockpit Noise.
1/3 octave spectrum.



Speech audiometry.

A Madsen Midimate 330 Audiometer (Madsen Electronics, 20, Vesterlundsvej, DK 2730, Herlev, Denmark) coupled to a personal computer was used for the audiological tests, using a Peltor aviation headset type MT32H7F-22 72 (Peltor, Box 2341, S-331 02 Värnamo, Sweden), adapted for the purpose by rewiring and fitting new plugs to separate channels. This is a widely used headset with good noise damping characteristics . Norwegian standard speech audiometry test material, prepared on digital audio tape, was used (Rikshospitalet, Oslo, Norway). We performed a one-syllable words test, as this in previous experiments has been shown to give the most reliable results (9).

Variations in the signal-to noise ratio in this study were obtained by varying the signal level above reference speech recognition threshold level through the audiometer, keeping the environmental noise constant (9). Each test was started with the first words presented at a level which had been tested to be well audible with headset only. 20 words were presented at each level, gradually reducing the level by 5 dB steps until almost inaudible. The environmental noise was kept constant.

Subjects were not trained in any way prior to the experiments. This causes an increased variability in the results, but is closer to an operational setting where unexpected words may be encountered. Furthermore, all words used are common in the Norwegian language so that subjects would not encounter unfamiliar or unknown words.

Subjective scoring

After the main experiment, each subject was asked to subjectively score the diferent ear plugs on a scale from 1 to 10 based on the combination of comfort, noise attenuation and speech sound quality. This was done on a Visual Analogue Scale (VAS) 10 cm long, with a marking for each cm.

Experimental conditions

Speech audiometry was performed 4 times for each subject, for each of the 4 experimental conditions: Headset only, foam plugs, HiFI plugs and custom-made plugs.

The foam plug has an overall attenuation of around 25 dB, with a better attenuation for higher frequencies.

The "HiFi" plug has an overall attenuation of around 15 dB with a slightly higher attenuation in the high-frequency range.

The custom-moulded plug is moulded to fit each subjects ear canals, and also has an overall attenuation of around 15 dB, with a nearly "straight" frequency response curve.

The sequence of conditions was randomised within a selected, balanced set of sequences.

Ear plugs were fitted by an ear, nose and throat specialist who supervised the subject inside the noise chamber. Neither the audiometry operator nor the subjects were allowed to see which ear plug was being inserted/ used.

Results

The mean ambient noise levels between experiments were between 104.2 and 104.3 dB leq (lin) for all experimental conditions, minimum and maximum levels for individual experiments being 104.0 dB and 104.6 dB respectively

Speech intelligibility scores for the headset only situation are shown in figure 2, showing 95% confidence intervals.

The wearing of foam plugs caused a very substantial decrease in word intelligibility for all levels. (fig.3).

This detrimental effect on intelligibility was also apparent for the "HiFi" plugs, although not to the same extent (fig.4).

The custom made ear plugs performed markedly better than the two other types og plugs (fig. 5), showing a word intelligibility score close to the headset-only situation.

Figure 2. Headset only. Speech intelligibility - Mean scores +/- 95% Confidence interval. N=9

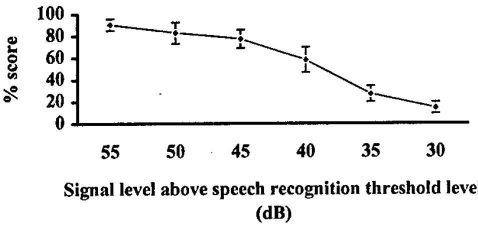


Figure 3. Headset and conbination headst/foam plugs. Mean scores +/- 95% Confidence intervals. N=9

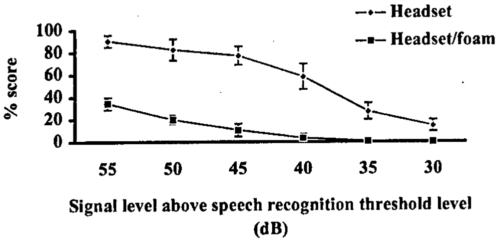


Figure 4. Headset and conbination headst/"HiFi" plugs. Mean scores +/- 95% Confidence intervals. N=9

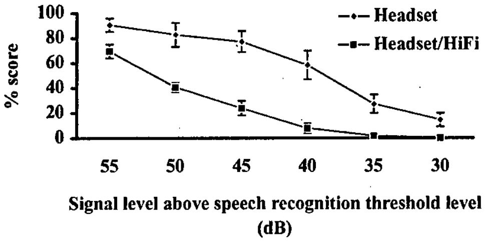
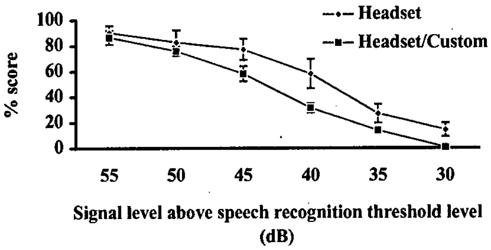


Figure 5. Headset and conbination headset/custom made plugs. Mean scores +/- 95% Confidence intervals. N=9



Mean total scores for the 4 experimental conditions are shown in figure 6, showing the differences even clearer. A one way ANOVA test showed a hghly significant difference between situations.

The subjective scoring based on a combination of comfort, noise attenuation and speech sound quality is represented in figure 7. In this figure mean Visual Analogue Scale (VAS) scores are shown. On this subjective scoring, the custom-made ear plug came out best and, notably, also better than the headset-only situation. A one-way ANOVA test showed that differences are highly significant.

Figure 6. Mean total scores for the four experimental conditions. Speech intelligibility. N=9. (ANOVA: p<0.001)

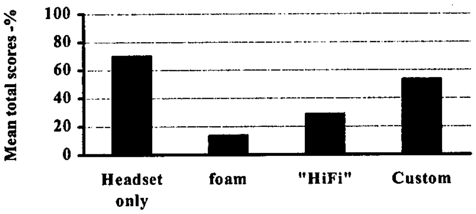
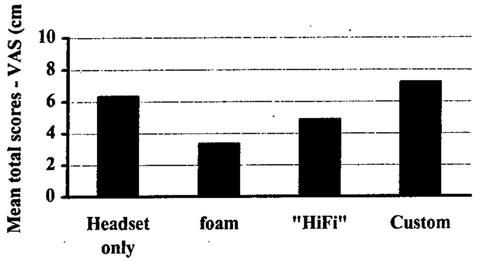


Figure 7. Subjective VAS scores. Comfort, attenuation and speech quality - N=9 (ANOVA:p<0.001)



Discussion

The mean ambient noise levels, varying only between individual experiments from 104.0 to 104.6. This small variability in noise levels rules out any significant adverse effects on results from variations in the noise environment.

The variation between subjects is reasonably low, shown by the 95% confidence intervals in figure 2, giving a good basis for comparisons between the experimental situations.

The foam plugs were shown to drastically reduce speech intelligibility when worn under the headset. (fig.3). The reason for this is probably a combination of two main factors:
Firstly, the addition of foam plugs inside the headset is likely to reduce the communication speech level more than the environmental noise. This is because the low frequency noise transmitted as bone conduction through the head becomes a factor. In other words, this seems to be a form of "overkill" in noise attenuation.
Secondly, the fact that foam plugs reduce high frequency noise more than low-frequency noise produces an even further reduction of the signal-to-noise ratio in frequencies important for speech understanding.
The somewhat better performance with the "HiFi"plugs as shown in figure 4 is probably due to a reduction of both the above factors.
There is a much improved speech intelligibility using the custom-made plugs (fig. 5) in comparison to the two other types of plugs (figs. 3 and 4 and fig. 6). Since overall noise reduction of these plugs and the "HiFi"plugs is similar (around 15 dB), the flatness of the frequency response of the custom-made plugs seems to be important. In other words, custom made plugs have a similar attenuation in all frequencies, thus avoiding selective degradation of the signal-to-noise ratio in certain frequencies.
The Visual Analog Scale scores (VAS), as seen in figure 7, shows that the subjects preferred the custom made ear plug to all the other situations, when considering comfort, attenuation and speech quality as a whole. This can only be due to the reduced total noise level, since speech intelligibility is slightly reduced as we have seen. A good noise attenuation is achieved without affecting speech communication too much.

Conclusions

Ear plugs may cause a large decrease in speech intelligibility when worn under the headset in helicopter noise.
Custom made ear plugs may provide a much improved attenuation over conventional plugs when worn under ear muffs, while maintaining good noise protection.

Custom made ear plugs might therefore be a good alternative to other forms of enhanced noise protection in helicopter.

Acknowledgements

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AN INSERT HEARING PROTECTOR WITH VOICE COMMUNICATIONS CAPABILITY

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SUMMARY

Helmets equipped with communications receivers contained within earcup enclosures have historically been the primary hearing protector and source of command input for aviators. There are inadequacies in this approach in terms of hearing protection and voice communications. The reduction of all noise levels reaching the ear to below 85 dBA, by using the helmet alone, is not attainable for all flight conditions in all U.S. Army helicopters. Earplugs worn in combination with the aviator's helmet do provide adequate protection from any Army noise environment, but sometimes at the expense of voice communications. Insert communication devices are a means of improving hearing protection while enhancing voice communications in noisy environments. Improving voice communications can improve overall performance, reduce stress, and increase situational awareness. Characteristics of insert communication devices being assessed in U.S. Army helicopters are discussed and compared with other means of enhancing hearing protection and communications. Development and fielding issues, along with results of field assessment of a large sample of the aviator population, are provided.

1. INTRODUCTION

Noise, an occupational hazard, is prevalent in the U.S. Army aviation setting. In almost all cases, noise levels in helicopters during flight exceed safe levels as specified by DA Pamphlet 40-501, "Hearing Conservation" [1]. Hearing protectors are included in conventional helmet design in the form of earcups that act as barriers between the user's ear and the ambient noise levels within the helicopter. In some helicopters, noise levels exceed the capability of the aviator helmet to provide proper and adequate hearing protection.

There are many constraints and requirements for today's aviator helmet. The original requirements that the helmet protect the aviator during crash and from excessive noise exposure have been matched by the need to provide the aviator with vital information displays. However, the addition of head-borne equipment creates a conflict between the concepts of providing protection during mishap and providing protection during aerial combat maneuvers.

Helmet designers must accommodate these requirements while not increasing the weight of the total ensemble beyond safe limits. Center of gravity and weight limits for U.S. Army aviator helmets are described by McEntire and Shanahan [2]. Helmets used by today's military aviator and combat vehicle crewman are a product of many years of compromise between helmet designers and combat developers. Early helmet designs were intended to provide protection from the elements. Equipment such as microphones and receivers was added to the helmet to enable communications when it was necessary. The need to communicate was probably the real impetus for sound attenuation--improving signal to noise improved the aviator's communications capability. Not until the 1950's and 1960's did improvements in hearing protection capability of helmets become a requirement as the effects of the military noise environment and its effect on hearing and communications were better understood. The sound protective helmet series, including the SPH-4 in the late 1960's, were probably the first designs directed primarily toward the protection of hearing. This was followed closely by the development of the DH-132 Combat Vehicle Crewman (CVC) helmet that also incorporated enhancements in hearing protection. The SPH-4 specification documents included significant improvements in impact protection properties, in addition to imposing severe limits on overall helmet weight, in order to enhance the survivability of helicopter crewmen involved in accidents.

The exposure of individuals to noise is based on the expected A-weighted sound level (dBA) arriving at the ear. Noise levels exceeding 85 dBA are defined as hazardous and require that hearing protection be worn [1]. The measured noise levels are used as the exposure level when the individual is unprotected. If hearing protection is worn, the noise exposure is calculated by combining measured noise with the measured sound attenuation, standard deviation, and A-weight factors for each octave band using the formula shown below. The result is an estimated exposure level (EEL) of A-weighted noise arriving at the listener's ear while in the noise environment. Noise hazard assessment procedures developed by the Army Medical Department (AMEDD) reduce the mean attenuation value [3,4] of the hearing protector by one standard deviation at each of the test frequencies when calculating the noise exposure level.

$$EEL = 10\,\mathrm{Log}\left(\sum_{125}^{8000} 10^{\frac{Noise\ Level_i - A\ Weight_i - (\overline{X}_i - 1SD)}{10}}\right)$$

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2. THE AVIATION NOISE ENVIRONMENT

The distribution of internal noise levels in dBA found in U.S. Army helicopters is shown in the Figure. It is based on about 400 records of noise measurements in Army aircraft for various flight conditions at various positions that may be occupied by crewmembers. This distribution shows that about 50 percent of the noise environments are above 100 dBA. In order to reduce the aviator's noise exposure below 85 dBA, hearing protection is provided by the helmet earcups or, in some cases, earplugs in combination with the earcups. Noise exposure levels indicate that about 15 percent of the conditions are above 85 dBA when wearing the aviator helmet. If earplugs are used in conjunction with the helmet, only 1 or 2 percent of the total distribution are above the 85 dBA noise exposure limit. Surveys conducted by the U.S. Army Aeromedical Research Laboratory (USAARL) indicate that about 80 percent of Army aviators currently wear earplugs in addition to their helmet.

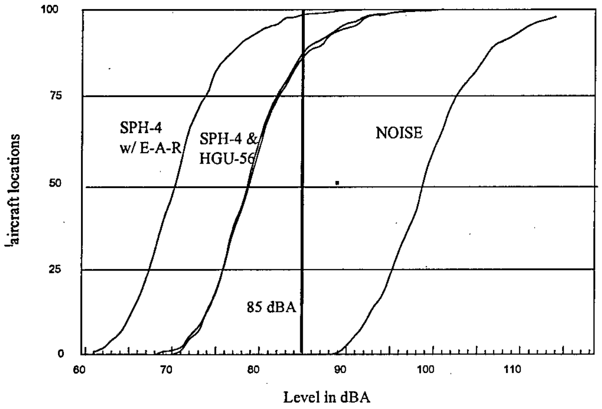

Figure. Noise level distribution of U.S. Army helicopters with noise exposure levels for aviators while wearing the SPH-4B, HGU-56/P and SPH-4B with yellow foam earplugs.

3. NEW HEARING PROTECTION TECHNIQUES

Maintaining the necessary hearing protection for Army noise environments while providing the best voice communications for the aviator has become the central goal of the hearing conservationist. In present-day Army aviation, voice communication is frequently reduced due to poor speech signals reaching the ear. Combination protection (i.e., earplug in addition to the helmet) is a technique commonly used to provide additional hearing protection, but this technique generally leads to decreased voice communications capability [5]. The combination of inadequate intercom system (ICS) output and the use of ordinary earplugs may be responsible for most of the poor speech signal to noise ratio.

Several methods of improving speech intelligibility and hearing protection are currently in development, and are being operationally tested with some limited fielding into actual military operations. Active noise reduction (ANR) techniques have been shown to improve both hearing protection and speech intelligibility [5]. The technique provides exceptional low frequency hearing protection, but does very little to improve protection for frequencies above 800 Hertz. ANR improves speech intelligibility when worn alone, but both hearing protection and speech intelligibility are degraded when worn with ancillary equipment such as spectacles or the chemical/ biological (CB) mask [5].

The communications earplug (CEP) is another technique that may be used to improve hearing protection and speech intelligibility. It incorporates a miniature earphone with a foam earplug and can be worn in combination with the aviator's helmet. Noise exposure estimates using hazard assessment procedures show the CEP provides adequate hearing protection for 8 hours of duty even in the high noise levels found in the CH-53, one of our noisiest helicopters [6]. The device also provides voice communication intelligibility that approaches 100 percent in those high noise environments. The CEP requires an additional step in the donning process and, for the non-earplug user, may require a short period of time to accommodate to the addition of something in the ear canal. Speech intelligibility test results are shown in Table 1. These tests were conducted while wearing spectacles or CB mask in conjunction with the hearing protector/communications device. Ambient noise levels simulated the UH-60 at 105 dBA. Speech levels were held constant for all of the test conditions.

Table 1. Mean and standard deviation of percent speech intelligibility for hearing protectors worn alone, with CB mask, and with spectacles at constant speech level.

Test condition	HGU-56/P	ANR1	CEP with HGU-56/P
Alone	57	93	89
	15.2	3.6	7.6
Spectacles	38	87	89
	20.7	10.0	5.4
CB mask	39*	75*	84
	24.4	23.3	12.1

*Ambient noise decreased by 10 dB

4. HSW AND HEARING PROTECTION

The weight of the helmet is critical when considering its ultimate effectiveness in today's military environment. Individuals riding in aircraft or ground vehicles can be subjected to significant forces on the head and neck because of head-supported mass [7]. These forces become critical during high accelerations of the head caused by rough terrain, direction changes to evade and escape, or mishaps. Table 2 shows the weight of each component of the CEP, the HGU-56/P and an ANR earcup system. Considering the weight savings, use of the CEP as a replacement of the earcup system would result in potential reduction of about 198 grams for the HGU-56/P or about 290 grams compared to an ANR communications system manufactured by Bose Corporation [5].

Table 2. Weight of the CEP compared to other helmet hearing protection/communications techniques.

Item	Weight (g)
CEP with HGU-56/P interface cable and blown-air port adapter	18.8
CEP	8.0
Interface cable	5.0
Blown-air port adapter	5.8
HGU-56/P earcup with foam inserts, 2990 earseal, and earphone (model 996) X 2	215.0
HGU-56/P earcup with foam inserts and 2990 earseal X 2	175.0
Earphone, model 996	19.8
ANR earcup and earseal X 2	308.4

5. USER INFLUENCE IN THE DESIGN

One of the most critical requirements of systems development is to define the worth and acceptability of the system to the user group. User acceptance tests should be performed by users in the operational environment or, at a minimum, a high fidelity simulation. Personal equipment, such as communications and hearing protective devices, must be assessed by as many users as possible, and in as many operational and environmental conditions as practical [6,8].

In 1997, a study [6] comparing the CEP and the HGU-84 (a Navy helmet) using Navy and Marine Corp aviators at Quantico, VA, was conducted. A questionnaire was used to solicit the volunteer's opinion of the CEP compared to their personal helmet. Comfort, compatibility, communications performance, utility, and overall value-added were the areas of interest. A 7-point rating scale was used to compare the CEP and the helmet used in CH-46 and CH-53 helicopters.

Table 3 shows the results of questionnaires administered at the mid-point of the study and at the end of the study. For most of the questions, results show slightly stronger preference for the CEP at the end of the study, indicating users found the CEP more acceptable with continued use. The fit and comfort of the CEP were judged to be the same as their standard helmet, indicating discomfort was not considered to be a factor by the user after 4 months of use. There was a difference in favor of the standard helmet in the donning/doffing process because of the extra step required to install the CEP. (In the author's experience, users become more proficient in the procedure with continued use of the CEP. Proper planning of events that take place in the donning process will limit or eliminate problems for even the most time critical mission start.) Subjects indicated a strong preference for the CEP over the standard helmet in all of the noise reduction and speech clarity responses.

6. CURRENT STUDIES

The U.S. Army is completing a field study of the utility and acceptability of the CEP in the OH-58D operational environment. Approximately 600 CEP devices have been issued to aviators for use during their normal aviation activities. Results from this study will be available in early FY99.

Table 3. Results of midpoint and final questionnaire assessments (15 subjects).

	Midpoint	Final
Average flight-hours using CEP	30.5	40.7
Fit and comfort of CEP	4.2	4.1
Donning/doffing	3.5	3.5
ICS clarity	6.3	6.5
Radio communications clarity	6.3	6.6
Gender clarity (male)	6.1	6.6
Gender clarity (female)	6.0	6.6
Overall clarity	6.3	6.6
Noise reduction	6.3	6.4
Ability to hear warning signals	6.0	6.6
Ability to hear environmental sounds	4.1	4.1
Overall value of CEP	6.1	6.3

Note: A numerical "7" rating indicated the user's highest preference for the CEP while a "1" rating indicated the user's highest preference for the helmet. If the user perceived no difference between the CEP and the helmet, the rating would be a "4."

Improvements in the physical characteristics of the CEP are a continuing priority. Changes in wiring materials are being evaluated to increase durability and extend the life expectancy. Improvements in size and characteristics of the transducer housing are also being considered.

7. CONCLUSIONS

ANR and CEP are viable approaches to improving aviator auditory performance while providing adequate hearing protection for Army noise environments. Both systems are far along in the development process and show promise for near term fielding. The CEP system is lightweight, cost effective, and does not require modification of aircraft wiring since the earphone element is of dynamic design. It is the author's opinion that the CEP approach provides the best solution for all aspects of helmet performance, including hearing protection and auditory function.

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Moulded Lumbar Supports for Aircrew Backache - Comparison of Effectiveness in Fixed and Rotary Wing Aircrew

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1. SUMMARY

1.1. Objective

To compare the effectiveness of the RAF aircrew individually moulded lumbar support in relieving postural backache in aircrew employed in different aircraft types.

1.2. Design

Postal questionnaire survey of all British military aircrew issued with lumbar supports for postural backache backache between 1 January 1986 and 31 January 1995.

1.3. Subjects

309 military aircrew categorised into 6 employment groups.

1.4. Outcome measures

Subjective assessment of relief of backache, improved flying performance, satisfaction with support provided.

1.5. Results

Of 329 questionnaires distributed to potential subjects 309 (93.9%) were returned. The support provided relief for between 62.9% and 91.7% of the groups of aircrew studied. Significant differences were found between ejection seat aircrew and helicopter pilots in improving backache ($p=0.020$ 95% exact CI +0.04 to +0.29) and in dissatisfaction ($p=0.014$ 95% exact CI +0.05 to +0.38). No significant differences were found for other measures, although results suggested that the supports impaired performance and induced dissatisfaction in mobile rear crew.

1.6. Conclusion

Further study is required to address the specific problem of backache in flight in helicopter pilots.

2. INTRODUCTION

Backache in aircrew is a frequent complaint and is a well-recognised problem in all seated workers. In most ground-based employment it is possible for a worker to relieve back discomfort by altering his or her position or by standing up from the seat. In most types of military aircraft the aircrew do not have such opportunities to ease their backache. Persistent backache in flight is a distraction from the operational task. It increases fatigue, impairs concentration, causes irritability and interferes with post-flight relaxation and sleep (1). It is one of many factors that can reduce the efficiency of aircrew; not only may it have an operational impact in that it may interfere with the success of a mission, but it may also have a direct effect on flight safety.

3. SITTING AND BACKACHE

3.1. The Anatomical Basis of Postural Backache

Man's transition from crawling infant to upright adult results in the change from a dorsally curved lumbar spine to the lumbar lordosis of his erect posture (Fig 1). From that transition comes his propensity to low back pain. When standing, the pelvis is rotated forward and the angulation of the sacrum creates a marked curve in the lower lumbar vertebrae. This curve is followed by both the bodies of the lower lumbar vertebrae and their intervertebral discs being wedge-shaped, deeper anteriorly than posteriorly. The flexibility of the lumbar spine relies upon the elasticity of the intervertebral discs.

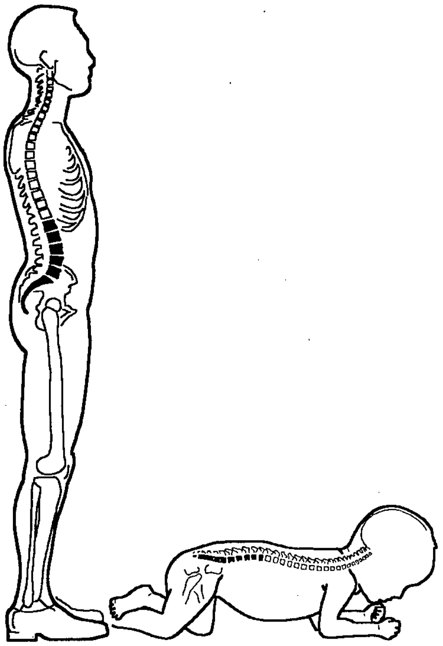

Fig 1. Change in lumbar lordosis with erect posture

The changes that occur in the lumbar spine on sitting were described by Keegan following a detailed radiological study of healthy young adults (2). Flexion

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of the hip joints extends the posterior thigh muscles. As they reach their maximum extension, at a trunk-thigh angle of approximately 135 degrees, the pelvis starts to rotate backwards. Extension of the knee, which increases tension in the hamstring muscles, also increases the rotation of the pelvis. This rearward rotation of the pelvis induces flattening of the lumbar curve (Fig 2). At trunk-thigh angles of 90 degrees or less the lumbar lordosis is obliterated and in some individuals becomes reversed. As the lumbar curve flattens the anterior portions of the intervertebral discs are compressed, generating an increasing hydraulic wedging pressure in the disc which tends to force the nucleus of the disc backwards. This tendency increases with age as the discs lose their elasticity and their nuclei become fibrotic. The deformed discs stretch the pain-sensitive posterior longitudinal ligament, causing pain in the mid-line of the lower back. This discomfort can be reduced by frequent postural changes, but prolonged sitting without postural change is likely to result in reflex contraction of the lumbar paravertebral muscles, thus increasing the backache.

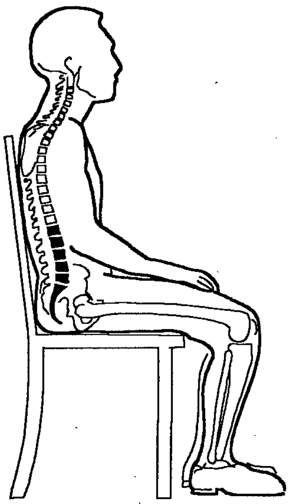

Fig 2. Flattening of the lumbar lordosis when seated

3.2. Supporting the Seated Worker

Keegan (2) suggested that the essential features of a satisfactory chair were support over the lower lumbar spine, a minimum trunk-thigh angle of 105 degrees, a recess below the lumbar support to accommodate the sacrum and buttocks, a maximum seat length of 16 inches (40.6 cm) measured from the front surface of the lumbar support to permit movement at the knee, a seat height of 16 inches or equivalent foot support and an upward inclination in the seat of 5 degrees to help in maintaining the proper position against the lumbar support. Akerblom (3) supported these principles and observed that a work seat providing a trunk-thigh angle of between 105 and 112 degrees should not produce an unacceptable reduction of the lumbar lordosis. Even in the ageing, those over thirty, he considered that sitting periods of several hours should not cause any serious pressure changes in the discs.

Williams and others (4) examined the importance of lumbar posture in sitting comfort. They observed that there was conflict in the literature, with some researchers advocating a kyphotic posture and others stating that a lordotic posture was essential. They demonstrated that a lordotic posture considerably reduced back pain in subjects who had a history of seated low-back pain whereas a kyphotic posture provided no benefit.

In his wide-ranging review of the seated work position Mandal (5) observed that modern furniture for use in schools, factories and offices is constructed in such a way that no one can use it properly. It is normal for seated workers to lean forward, adopting a kyphotic posture. Children naturally resist this posture by sitting on the front edge of the seat, tipping the chair forwards onto its front legs. He also observed that the optimal seated posture appeared to be achieved in horse riding, where the trunk-thigh angle is approximately 135 degrees and which, as already noted, results in no loss of lumbar lordosis.

The advantages of the horse riding posture were also described by Gale and others (6). They specifically examined industrial workers whose work involved use of the arms in front of the body rather than the desk workers discussed by Mandal (5). They used a saddle shaped seat which provided a trunk-thigh angle of approximately 135 degrees and which avoided the tendency for the worker to slide forward which can occur with forward sloping seats. They concluded that the saddle seat offered appreciable benefits.

3.3. Seats for Aircrew

There are a number of constraints to seat design in aircraft that preclude the use of innovative seats. In fast jet aircraft the seat is also an escape system. Forward tilting seat pans could not be tolerated during the high accelerations experienced during ejection as they would cause the aircrew to slide forward, flexing the lower spine and increasing the likelihood of spinal compression fractures. Pilots are required to use their feet to operate rudder or tail rotor controls and toe brakes. In these circumstances the legs cannot be used to prevent the pilot sliding forward in a forward sloping seat.

Within these constraints, it is important that aircrew seats are designed to provide optimal lumbar support, thereby encouraging a lordotic posture, and to provide a seated position that does not rely on limb counter pressure for stability.

4. POSTURAL BACKACHE IN AIRCREW

4.1. First Description

In 1968 Fitzgerald (7) observed that inadequacies in the design of aircrew seats increased the likelihood of excessive pelvic rotation and that the seats provided poor low back support. In the case of ejection seats, back support was compromised by the positioning of survival equipment.

At the time survival packs, containing dinghies and other aids to survival following escape from the aircraft in flight, were packed in canvas and mounted in the seat pan, covered in a thin cushion. The seat occupant was often provided with an uneven, poorly contoured seat cushion. Parachute packs were mounted in the backrest of the seat, pushing the thoracic spine forward and leaving the lumbar spine poorly supported.

In addition, the geometry of restraint harnesses was unsatisfactory. Lap straps were attached to the seat at the junction of the seat pan and backrest. Their route around the upper anterior portion of the iliac crests tended to elevate the front of the pelvis, increasing posterior rotation and further reducing lumbar lordosis. In many seats the shoulder harness attachment was below the level of the shoulders, causing spinal compression, especially in tall aircrew.

In transport aircraft and helicopters flat-backed seats with excessively soft cushioning materials were common. The bottoming of the cushion under the buttocks increased the trunk-thigh angle and forward creep separated the buttocks from the seat back. The resultant spinal flexion exaggerated the normal loss of lumbar lordosis in the sitting position. These problems are illustrated in Fig 3.

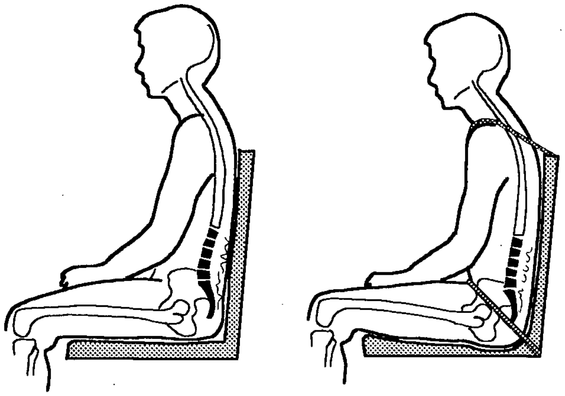

Fig 3. Pelvic rotation and spinal compression due to harness position, "bottoming" and "creep".

Fitzgerald suggested that by introducing modifications to aircraft seats, including adjustable, contoured lumbar support and adjustable thigh support, the the trunk-thigh angle could be improved, thereby restoring the normal lumbar lordosis.

Fitzgerald went on, with Crotty (1), to quantify the incidence of backache in aircrew. Their study of 1000 Royal Air Force aircrew and 1000 ground personnel matched for age found that the incidence of backache in aircrew was approximately twice that in ground personnel. The difference was consistent up to the age of 35 after which the incidence in both groups and the difference between the groups decreased. The incidence and difference increased again over the age of 45.

They found that in over half of the aircrew who suffered backache the sole cause was the cockpit environment: the inadequate design of aircraft seats, the geometry of the seat harness, the aircrew equipment worn or the ergonomics of the operating environment. In ejection seat and transport aircrew the pain was typically in the lower lumbar region and the principal factors were the seat design and harness geometry. For helicopter pilots the pain was usually at the thoraco-lumbar junction and at the base of the right shoulder blade. In this group the posture required to control the aircraft and the nose-down attitude of the aircraft in flight, compounded by the geometry of restraint harnesses, appeared to be of more importance. The characteristic posture of the helicopter pilot has been described by Braithwaite and Vyrnwy-Jones (8)

"Normally he first adjusts his seat so that operation of the pedals is possible. He then rests his right forearm on his right thigh to enable more precise control of the cyclic stick by the right hand. The left hand then rests on the collective lever which is adjacent to the left hand side of the seat. The left shoulder is forced to drop and the spine is rotated to the left. The normal cruising attitude of the helicopter (4 degrees nose down for the Gazelle) compounds the problem. The upper torso being tipped forward against the restraint provided by the shoulder and lap belts."

4.2. Studies of Helicopter Aircrew

Several investigators have examined backache in helicopter pilots, but there is much less information on ejection seat and transport aircrew. There is also some conflict in the findings of workers in this field. van Leusden, Prendergast and Gray (9), in a review of causes of medical restriction on flying duties in Canadian Forces pilots, reported that backache was the second most common cause of restriction, but did not discuss aircraft type.

In their study of British Army Air Corps pilots Braithwaite and Vyrnwy-Jones (8) found that 82% of 99 pilots suffered from backache in the Gazelle helicopter. Factors identified as contributing to this incidence were excessively soft seat cushions, a lack of lumbar support and poor restraint harness geometry. They drew particular attention to the low seat attachment point of the shoulder harness in the Gazelle and the resultant compression of the helicopter pilot's flexed, scoliotic spine.

Shanahan, Mastroianni and Reading (10) obtained similar results in their study of 802 United States Army helicopter pilots. 72.8% of pilots reported back pain in flight over a period of 2 years; almost half of the subjects had pain in at least a quarter of their flights. They drew particular attention to the poor operating posture adopted by the helicopter pilot. However, they did not find the pattern of pain characterised by Fitzgerald and Crotty (1); nearly three-quarters of the subjects reported low back pain, a third reported numbness in the buttocks and less than 10% reported mid or upper back pain.

In his study of Indian Air Force pilots flying the Chetak helicopter (the Indian military version of the French Alouette III), Randir Singh (11) found that all of his 21 subjects experienced backache in sorties exceeding 1½ to 2 hours. His subjects highlighted their posture as the main cause of their pain and by he demonstrated that poor lumbar support and a limited range of seat adjustment were the principal factors leading to backache. Poorly balanced flying controls, requiring continuous pressure on the right rudder pedal, also had an adverse effect on posture.

Froom and others (12) examined the backache experienced by Israeli Air Force pilots in the AH-1 helicopter. They compared flying in the pilot's seat, with the normal helicopter pilot's posture, and in the gunner's seat, where the controls encouraged a more upright posture without rotation. All subjects flew in both positions. Both operating positions were associated with backache, but flying in the pilot's seat resulted in a greater incidence and severity of backache.

4.3. Vibration as a Causal Factor

Schulte-Wintrop and Knoche (13) found in a questionnaire study that 40% of crew members in the German UH 1-D helicopter, including pilots, flight engineers and medical escorts, reported backache in flight. They concluded that vibration, posture, draughts and a lack of remedial exercises were relevant factors. Their study was, however, based solely on the opinions of the respondents and made no assessment of the flying environment.

In a similar study in the former Republic of Yugoslavia Colak, Jovelic and Manojlovic (14) found that 53% of helicopter pilots and 50% of helicopter flight engineers had low back pain, compared with 36% of air traffic controllers. They went on to analyse the vibration environment of the three helicopters flown by their subjects, which they then quantified in accordance with ISO 2361 (0). They took the view that vibration did not play a significant role in causing low back pain.

The perception that vibration is a contributory factor in the causation of backache in helicopter pilots has often been included in aviation medicine teaching. However, Stott (16) observed that, although whole body vibration has clearly been implicated in provoking backache and long-term lumbar spinal damage in vehicle drivers (17), whole body vibration in helicopters is not usually at spinal resonant frequencies. Wilder and his colleagues (18) demonstrated that the vertical resonant frequencies of the normal spine were at approximately 5, 10 and 13 Hz.

The UK Ministry of Defence has conducted internal experimental studies on the vibration spectra of British military helicopters. In the SeaKing there are low energy peaks at 4 and 6 Hz which cause spinal resonance at 5 Hz. The Lynx has a peak at 1-2 Hz, and then a very low energy vibration spectrum until the principal peak at about 22 Hz. The Chinook has peaks at 4, 8, 12, 16 and 24 Hz; however, this aircraft is fitted with a vibration damping seat which isolates the pilot from low frequency vibration.

Shanahan and Reading (19) studied a small group of experienced United States aircrew operating a helicopter simulator. The subjects, all of whom had histories of backache in flight, occupied a flight deck mock-up, mounted on a multi-axis vibration simulator, for two periods of 2 hours each. One simulated flight period was conducted without vibration, the other with a vibration input recorded from the pilot's seat mounting rail in flight. All subjects experienced back pain which they confirmed was comparable with their in-flight pain, but no difference was detected between vibration and no-vibration conditions except in one subject. From these findings Shanahan and Reading suggested that it was unlikely that backache in helicopter pilots was influenced by exposure to vibration.

Froom and others (20) compared back pain in Israeli fighter (ejection seat), transport and helicopter pilots. They found that 34.5% of helicopter pilots, 12.9% of fighter pilots and 4.8% of transport pilots had backache in flight, but chronic back pain was twice as common in fighter pilots as it was in the other two groups. They could not draw a conclusion for causes of the chronic pain in fighter pilots, but suggested that there was little evidence to support the belief that vibration in helicopters caused long-term spinal damage.

In the Netherlands Bongers and others (21) conducted a detailed questionnaire study of 163 helicopter pilots and 297 non-flying air force officers. They found that the helicopter pilots had significantly increased short-term backache, chronic backache and radiating leg pain, but no increase in pathological back lesions when compared with the non-flying controls. Short-term back pain was related to the frequency and duration of flight, whereas chronic back pain was related to total accumulated flying hours. They also analysed the vibration environment of the four helicopter types flown by their subjects (Alouette III, Bolkow 105, Sikorsky 61 and Sikorsky 76). In all types the peak frequencies were above the primary vertical resonant frequency of the spine. However, they provided no information in their paper on the frequency spectra of the aircraft and man-mounted measurements were not performed. They thus failed to assess the true dynamic behaviour of the man-seat system. Nevertheless, they assessed vibration doses under ISO 2361/1 (22) and the then new first draft ISO/DP2361 (23). Using that methodology they demonstrated a dose relationship between vibration and chronic back pain.

These conflicting studies provide no definitive evidence that vibration is a causal factor in the genesis of aircrew backache. However, the finding of spinal resonance in some aircraft types suggests that it may well be a significant factor for some helicopter pilots.

4.4. The Contribution of Sustained Acceleration

Burmeister and Thoma (24), in a study of German jet (Alpha Jet) and propeller (Piaggio 149 and Dornier 28) aircraft pilots, found that half of their 88 subjects suffered back pain in flight. One third of the jet aircraft pilots reported aggravation of their back pain when exposed to +Gz acceleration and a fifth with turbulence; a few mentioned vibration. None of the propeller aircraft group expressed any awareness of +Gz acceleration, turbulence or vibration as being a factor in their back pain.

Froom, Margaliot and Gross (25) examined the effect of +Gz acceleration in more detail by relating radiological changes in the lumbar spine with symptoms of lumbar pain in Israeli fighter, helicopter and transport aircrew. They found that fighter pilots had an increased prevalence of low back pain with radiation to the leg compared with the other two groups; this finding was associated with narrower disc spaces in fighter pilots. In addition, they observed that fighter pilots without back pain also had narrower disc spaces. They suggested that this finding could well be associated with the exposure to sustained +Gz acceleration which is an integral part of fighter operations.

4.5. Backache in the Mobile Crewman

A further group of aircrew that has been almost ignored in the literature is the mobile crewman. In transport aircraft, support helicopters and search and rescue helicopters the crewman spends part of his time seated and part mobile. This group includes loadmasters who manage freight and passengers in the aircraft and underslung loads outside it, winchmen and winch operators in the search and rescue role, and in-flight medical escorts. Schulte-Wintrop and Knoche (13) included medical escorts in their study, but did not distinguish them from other subjects. Gee specifically included mobile rear crew in an unpublished study of Royal Air Force and Army helicopter aircrew (26). He found that 52.9% of support helicopter crewmen reported that they regularly suffered backache in flight.

There appear to be factors in this group other than the seated posture. In some helicopter cabins there is insufficient headroom to stand erect and the lack of headroom is aggravated by helmet-mounted electro-optical devices. In addition, crewmen often work kneeling and may be required to move heavy objects inside and outside the aircraft cabin. Search and rescue crewmen and medical escorts, by the nature of their role, are required to handle stretchers in difficult and cramped conditions both inside and outside the aircraft.

4.6. In Summary - A Universal Problem

These studies demonstrate that low back pain is a common, international problem for military aircrew and that it occurs in all aircraft types and all aircrew roles. In all types and in all roles except, perhaps, the mobile crewman the seated posture is the principal cause of back pain.

The effect of the flattening of the lumbar lordosis is compounded by a number of factors. These include the design of and materials used in aircrew seats, and the geometry of restraint harnesses. Vibration may play a part, although it is probable that this is an aircraft type specific problem, particularly in some helicopters. Sustained acceleration may contribute; any increase in wedging pressure in the lumbar intervertebral discs likely to have an influence. Although the role of sustained acceleration has not been clearly demonstrated, it is logical to accept that it is a likely contributor. The flexed, rotated spine of the flying posture in helicopters is particularly unsatisfactory.

4.7. The Two Syndromes

There is ample support for Fitzgerald's and Crotty's (1) assertion that there is not a single syndrome of postural backache in military aircrew. Rather, it is likely that there are two principal syndromes: "ejection seat back", typically affecting aircrew who are restrained throughout flight and whose posture is upright, and "helicopter back", provoked by a flexed, rotated posture.

Other groups of aircrew who suffer from postural backache in flight, such as light aircraft and transport aircraft pilots, have an operating position more in common with the man in the ejection seat than with the helicopter pilot and could be expected to suffer a similar type of backache.

A small group, the rear crew in maritime patrol aircraft, airborne warning and control aircraft and anti-submarine helicopters, are required to operate desk mounted consoles fitted with display screens. This subgroup of static rear crew has more in common with office workers than with other groups of aircrew. In addition, mobile rear crew appear to suffer backache which may be related to factors other than seated posture.

5. THE ROYAL AIR FORCE AIRCREW LUMBAR SUPPORT

5.1. Introduction of the Support

Fitzgerald, drawing on his earlier work with Sharp and Barwood (27) in developing a rapid method of casting body contours, produced an experimental individually moulded lumbar support for aircrew. Supports were issued to 50 aircrew, of whom 36 flew in ejection seat aircraft and 4 in helicopters (28). Two subjects had little or no benefit; one had suffered spinal injury in an aircraft accident, the other had early ankylosing spondylitis.

In 1973 Fitzgerald (29) reported the development of a production version of his moulded support. Since then, British military aircrew suffering from postural backache with no underlying pathology have been offered an individually moulded lumbar support to wear in flight. In addition, the support has been offered routinely to aircrew with spinal pathology, such as treated prolapsed intervertebral disc or healed vertebral fractures following ejection, on the recommendation of the orthopaedic surgeons responsible for their care.

5.2. Effectiveness of the Support

Aircrew who are fitted with a rigid lumbar support are requested to return a questionnaire after wearing the support in flight for a period of 2 months. A proper analysis of these questionnaires is difficult: the return rate is less than 50% (unpublished information) and the period of use reported is short. Reader analysed those questionnaires that were returned over the two years 1983-4 (30). The results of this study should be treated with some caution since the return rate of the questionnaires was only 36%; nevertheless, 90% of subjects reported improved sitting comfort and 97% reported a reduction in backache.

Anecdotal reports from a number of Royal Air Force medical officers responsible for the medical supervision of aircrew suggest that the moulded support is, indeed, effective in ejection seat aircrew. However, there is also a strong impression that it is much less effective in helicopter pilots. Although Fitzgerald included helicopter pilots in his studies, the design of the Royal Air Force rigid lumbar support was primarily centred around the deficiencies of ejection seats and flight deck seats in transport aircraft.

6. AIM

This study was intended to compare the effectiveness of the individually moulded lumbar support in ejection seat aircrew with its effectiveness in other aircrew groups.

7. METHOD

7.1. Selection of Subjects

Details of all currently serving British military aircrew issued with individually moulded lumbar supports between 1 January 1986 and 31 January 1995 were obtained from records held at the Royal Air Force Aviation Medicine Training Centre, where supports have been manufactured since 1976. No reliable earlier records were available and later issues were discounted to ensure that all study subjects would have had the support available for use for at least 6 months. Only individuals who had been referred for treatment of postural backache were included, those whose supports were issued for pathological reasons were excluded. Reasons for exclusion included spinal fracture following ejection, prolapsed intervertebral disc, spinal malformation (eg spondylolisthesis) and previous spinal surgery. The current locations of all potential subjects were obtained from the personnel records offices of the Royal Navy, Royal Marines, Army Air Corps and Royal Air Force.

7.2. Administration of Questionnaires

The questionnaire used in this study was a simplified version of the questionnaire used by the Royal Air Force Aviation Medicine Training Centre as reported by Reader (30). That questionnaire addresses a number of issues including the severity, duration and frequency of pain, the convenience of the support, its stability in flight, the subjects awareness of its presence, and its effect on fatigue. For this study the only measures of interest were the aircraft type and flying role, the effect of the support on pain and the effect of the support on performance. Given that the questionnaire was a simplification of an existing questionnaire, no pilot study was undertaken.

The questionnaire sought answers to two questions:

> Has wearing a rigid lumbar support reduced, left unchanged or increased the severity of your symptoms of backache in flight?
>
> Has wearing a rigid lumbar support improved, left unchanged or impaired your ability to perform your flying duties?

The questionnaire requested details of the subjects aircrew role and information on the aircraft types in which the support had been most used. It also provided the subjects with an opportunity to comment on the rigid lumbar support.

Questionnaires were distributed to subjects through the military postal system, which provides a means of forwarding mail to personnel who have been posted to a new location or who are temporarily detached from their usual unit. A second copy of the questionnaire was sent to all subjects who failed to respond to the first distribution.

7.3. Study Population Groups

Respondents were allocated into 6 groups:

> Pilots and navigators who fly in an ejection seat equipped aircraft.
>
> Helicopter pilots.
>
> Light aircraft pilots.
>
> Large fixed-wing aircraft pilots.

Static rear crew. That is, aircrew in large bodied aircraft and helicopters, other than pilots, whose duty is primarily seated (principally navigators and flight engineers in transport aircraft, rear crew in maritime patrol and warning and control aircraft, and rear crew in antisubmarine warfare helicopters).

Mobile rear crew. That is, rear crew in transport aircraft and helicopters whose duty is primarily mobile (principally helicopter and tactical transport crewmen, and search and rescue winch operators and winchmen).

7.4. Categorisation of Responses

As the objective of the study was to assess whether or not the support was effective, responses of "reduced backache" or "improved performance" were classified as "effective". Other responses, where no benefit was obtained, were classified together as "ineffective". The inclusion of comments on the efficacy, design or convenience of the support was recorded and comments were classified as positive or negative. Where a subject made both positive and negative comments both were recorded. Multiple positive or negative comments from a single subject were counted as a single positive or negative comment, as appropriate. Comments not directly related to these factors were noted but not classified.

7.5. Statistical Analysis

Given the known effectiveness of the lumbar support in ejection seat aircrew, the ejection seat group was taken as the control population with which to compare results from the other groups. This approach permitted comparisons using 2x2 tables. By studying the entire population rather than a sample (or more correctly a large proportion of the available population) any differences found to be statistically significant could confidently be taken to represent a real difference. On the other hand, any lack of significance could not be taken to demonstrate that no difference exists between groups.

The number of subjects in some groups was very small and in some cases responses included zeroes. Statistical significance was assessed using Fisher's exact method. 95% exact confidence intervals (CI) were also calculated. Calculations were performed using a computer based statistical program (31) run on an IBM-compatible personal computer.

8. RESULTS

8.1. Response to the Questionnaire

338 questionnaires were issued of which 8 were returned by military postal offices because the subjects could not be traced. One questionnaire was returned with a statement that the subject had withdrawn from aircrew duties shortly after issue of the lumbar support. Of the remaining 329 questionnaires 277 were returned in response to the initial distribution. The second distribution of questionnaires to non-responders brought the total return to 309 (93.9%).

Three responses were excluded because essential information was omitted (aircraft type and duty in one case, responses to the questions in two cases). One subject responded only to the question on the effectiveness of the support on his backache and not to the question on its effect on performance of flying duties. Six subjects, 5 pilots (of whom 2 were test pilots) and a crewman instructor, indicated a clear change of flying role or regular employment in more than one role and gave responses for each role in which they had worn the lumbar support; they also gave a clear indication of prolonged use in all the roles in which they had been employed. These responses were taken as separate responses. In all there were 316 responses from 306 subjects, of whom one was female. 241 (78.8%) of the subjects chose to make comments, of whom 205 made comments specifically related to the support; the remainder made comments about cockpit or seat design.

8.2. Analysis of Responses

Results for effectiveness in reducing backache are given in Table 1. No significant difference was found between ejection seat aircrew and other aircrew groups except

Role	Total	Effective	Ineffective	Probability	95% CI
Ejection Seat Aircrew	59	47 (79.7%)	12 (20.3%)		
Helicopter Pilots	167	104 (62.3%)	63 (37.7%)	0.020	+0.04 to +0.29
Light Aircraft Pilots	12	11 (91.7%)	1 (8.3%)	>0.5	-0.36 to +0.19
Large Fixed Wing Pilots	27	21 (77.8%)	6 (22.2%)	>0.5	-0.20 to +0.24
Static Rear Crew	46	35 (76.1%	11 (23.9%)	>0.5	-0.14 to +0.21
Mobile Rear Crew	5	2 (40.0%)	3 (60.0%)	0.159	-0.15 to +0.77

Table 1. Probability of a difference in effectiveness of the support in reducing backache in flight when compared with ejection seat aircrew.

helicopter pilots. The rigid lumbar support was found to reduce backache in 47 of 59 ejection seat aircrew (79.7%). For helicopter pilots the support was found to be effective in 104 of 167 subjects (62.3%). This was significantly different (p=0.020, 95% exact CI +0.04 to +0.29) from the effectiveness in ejection seat aircrew. The exact CI for all other groups spanned zero.

Table 2 details the results for effectiveness in improving performance of flying duties. No significant differences were detected between ejection seat aircrew and the other aircrew groups. However, for mobile rear crew the 95% exact CI of +0.09 to +0.32 suggested that the support was less effective in this small group.

The details of the nature of comments made are given in Table 3. Ejection seat aircrew made 32 positive and 14 negative comments whilst helicopter pilots made 62 positive and 69 negative comments. This difference was significant (p=0.014, 95% exact CI +0.05 to +0.38). For all non-significant results exact CIs were found to span zero, except in mobile rear crew where the 95% exact CI for a higher proportion of adverse comments was +0.39 to +0.70.

The distribution of responders and non-responders by aircrew role was checked. Figures are given in Table 4. The records used to obtain role information for non-responders cannot be regarded as wholly reliable since a few aircrew in this study are known to have changed role since their supports were issued. However, there were no significant differences in the distribution of aircrew roles in the two groups.

9. DISCUSSION

9.1. Questionnaire Design

This study set out solely to examine the possibility of qualitative differences in the effectiveness of the rigid moulded lumbar support in different groups of aircrew. To that end it was concerned with the gross subjective assessments of the aircrew concerned and was not concerned with quantifying degrees of effectiveness. The essential questions were "does the support make your backache better?" and "does the support improve your ability to do your job?".

The question on aircraft type offered the greatest opportunity for confusion in the analysis of responses. Its wording invited multiple responses and, not surprisingly, obtained some. Fortunately those aircrew who recorded aircraft from more than one group, for example ejection seat and large fixed wing types, were those who also provided details of the effectiveness of

Role	Total	Effective	Ineffective	Probability	95% CI
Ejection Seat Aircrew	59	19 (32.2%)	40 (67.8%)		
Helicopter Pilots	166	59 (35.5%)	107 (64.5%)	>0.5	-0.19 to +0.12
Light Aircraft Pilots	12	7 (58.3%)	5 (41.7%)	0.170	-0.62 to +0.08
Large Fixed Wing Pilots	27	8 (29.6%)	19 (70.4%)	>0.5	-0.21 to +0.24
Static Rear Crew	46	15 (32.6%	31 (67.4%)	>0.5	-0.20 to +0.19
Mobile Rear Crew	5	0 (0%)	5 (100.0%)	0.320	+0.09 to +0.32

Table 2. Probability of a difference in improvement in performance of flying duties whilst wearing the support when compared with ejection seat aircrew.

Role	Number commenting	Total comments	Positive	Negative	Probability	95% CI
Ejection Seat Aircrew	41	46	32 (69.6%)	14 (30.4%)		
Helicopter Pilots	111	131	62 (47.3%)	69 (52.7%)	0.014	+0.05 to +0.38
Light Aircraft Pilots	6	8	6 (75.0%)	2 (25.0%)	>0.5	-0.46 to +0.37
Large Fixed Wing	14	18	10 (55.6%)	8 (44.4%)	0.440	-0.16 to +0.43
Static Rear Crew	30	35	18 (51.4%)	18 (48.6%)	0.152	-0.06 to +0.40
Mobile Rear Crew	3	3	0 (0%)	3 (100%)	0.074	+0.39 to +0.70
Total	205	241	128	113		

Table 3. Probability of a difference in the proportion of positive and negative comments when compared with ejection seat aircrew.

Role	Responders	Non-responders	Other	Total
Ejection Seat Aircrew	56 (90.3%)	6 (9.7%)		62
Helicopter Pilots	164 (95.3%)	8 (4.7%)		172
Light Aircraft Pilots	11 (100%)	0 (0%)		11
Large Fixed Wing	22 (88.0%)	3 (12.0%)		25
Static Rear Crew	45 (93.8%)	3 (6.2%)		48
Mobile Rear Crew	5 (100%)	0 (0%)		5
Multiple roles	6			6
Not delivered			8	8
Not aircrew			1	1
Total	309	20	9	338

Table 4. Responses by aircrew role.

the support for each type separately. In the case of an Army flying instructor, two test pilots and a crewman instructor the additional information given included total hours flown on each type.

One subject failed to answer the question on the effect on performance and one subject failed to give details of his flying role. Five returns were blank, but all came from the follow-up of non-responders; this group was requested to return the form if they did not wish to complete the questionnaire. A number of helicopter rear crew gave multiple responses to describe their flying role. This was an expected result as there is considerable overlap and variety in rear crew duties amongst aircrew who share identical job titles. Allocation to the study categories of static and mobile rear crew in particular inevitably relied on the author's specialist knowledge of the nature of aircrew employment.

Analysis of the questionnaires thus suggests that the questionnaire design was satisfactory to achieve the objective of the study. However, its effectiveness relied on the intelligence and interest of the subjects.

9.2. Potential Confounding Factors

There were a number of factors that might be perceived as confounding the achievement of the study's aim. The populations studied were inherently disparate. The recruiting and selection policies of the Royal Air Force, for example, specifically discriminate between the aptitudes and personalities of candidates for aircrew employment. The assessment tests used for pilots and navigators differ. Pilots are required to have a high degree of hand-eye co-ordination and spatial awareness whereas navigators are required to have greater ability in computational skills. Furthermore, during pilot flying training personality has an appreciable impact on selection for flying role.

The subjects in the study were not matched for demographic variables. Such matching would have relied on a smaller sample size and some groups would have been excluded. For example, assuming an 80% response rate to the questionnaire, a study seeking to demonstrate a 20% difference between groups would have required a sample size of 60 in each group. This would have excluded all except ejection seat aircrew and helicopter pilots and would have required that the entire ejection seat aircrew population available be matched.

By conducting a whole-population unmatched study, sample size factors cease to be relevant. Although personality or demographic differences between the groups might have affected the outcome of the study those factors could reasonably be regarded as possible contributors to the efficacy or lack of efficacy of the support in the groups, rather than confounders to render the results doubtful.

9.3. Consideration of the Results of the Study

The very high response rate in this whole population study permits the assumption that significant differences between groups represent true differences. The results support the belief that the rigid lumbar support is less effective in helicopter pilots than it is in ejection seat aircrew. They also suggest that mobile rear crew perceive the support to have little benefit, although the small number in this group requires any such inference to be made with caution.

This study confirms that the individually moulded lumbar support is effective in the majority of seated aircrew with effectiveness in relieving backache reported between 62.3% in helicopter pilots and 91.7% in light aircraft pilots. However, there is a significant number of helicopter pilots in whom the support is ineffective. There is, therefore, a need to explore alternatives for this group.

9.4. Alternatives to the Rigid Lumbar Support

A number of alternatives to the current support exist. The inflatable cushion introduced following Braithwaite's and Vyrnwy-Jones' report (8) is widely used, particularly in the Army Air Corps and by Royal Air Force Gazelle pilots. Neoprene lumbar belts as used by athletes have been tried by a few individuals. Several comments were made about a variety of inflatable and foam rubber lumbar supports, some of which were obtained through military supply sources, with which individuals had experimented in the air.

The provision of protective equipment, in this case moulded lumbar supports, should be the last option in resolving the problem of postural backache in aircrew. A preferable approach would be to address the cause of the backache by examining and improving the design of aircraft cockpits and aircraft seats.

9.5. Changes in Seat Design

Much effort has gone into improving the lumbar support and comfort of ejection seats. Survival equipment has for some time been packed in contoured, rigid-topped containers which forms the support for the seat cushions made of stable materials. Parachute packs have changed from manually packed canvas containers fitted in the backrest of the seat to pressure packed head boxes which also provide head support during ejection. Most recent ejection seats include a contoured back rest and when first introduced into service drew much favourable comment from aircrew. However, lumbar support in these seats is not normally adjustable in depth or height in relation to the seat pan. Although several respondents commented on the improvement in ejection seat comfort in modern aircraft, a few individuals expressed very strong views on the inadequacy of the in-built lumbar support provided.

The geometry of restraint harnesses has been improved. Lap straps are now usually attached to the seat in front of the junction between the seat pan and backrest and are thus routed over the top of the thigh in the inguinal fold rather than around the anterior pelvic brim. The introduction of a fixed-length “anti-G strap” to prevent “submarining” under the harness in forward deceleration or during ejection ensures that the harness box is held low over the front of the pelvis, thereby reducing the tendency to exaggerate the posterior rotation of the pelvis. Shoulder restraint attachments have been moved higher up the back of the seat and most individuals can be accommodated without experiencing spinal compression.

In large fixed-wing aircraft there is considerable variety in the seats provided. Modern transport types, developed from commercial airliners, have adjustable flight deck seats which draw many of their design features from developments in chairs for office workers. The redesign of flight deck crew seats in the Nimrod maritime patrol aircraft, introducing a considerable range and choice of user adjustment, was a repeated source of favourable comment from pilots operating that aircraft. In all cases the new seat had removed any need for additional lumbar support. In contrast, the rear crew seat in the same aircraft was a source of repeated and bitter comment. Aircrew operating other large fixed-wing aircraft made a number of comments on the quality of seats in specific types, most adverse comments being generated by older aircraft.

9.6. The Helicopter Cockpit Environment

In helicopters a fundamental problem is the geometry of the flying controls. Fine control of the cyclic control column requires the pilot to rest his right forearm on his thigh. This inevitably forces him to adopt the typical helicopter pilot’s posture. The problems this generates are compounded by seat and harness design faults.

The introduction of armoured seats to protect the pilot from ground small arms fire has altered the geometry of the flying position by pushing the pilot upwards and forwards. The weight of anterior body armour increases the flexing forces on the thoracic spine. The use of night vision goggles reduces headroom, particularly for tall pilots. In addition, the mass of helmet-mounted devices has increased loads in the cervical and thoracic spine. All these aspects worsen posture and increase discomfort.

Recent design developments in helicopter flying controls should introduce fly-by-wire systems with sidestick controllers replacing conventional cyclic and collective levers. The introduction of such technology is likely to have a significant effect on the incidence of "helicopter back".

9.7. Options for Change

The high return rate of the questionnaire and the frequency with which subjects made both positive and negative comment on the existing lumbar support suggest that the subject of backache in aircrew is emotive. Given that backache in flight is a common distraction and, therefore, a hazard to safe operations, it is important to address the faults of existing crew seats and the ergonomics of the flying controls when introducing new aircraft types.

In new aircraft and in existing large fixed-wing aircraft there are ample opportunities to provide engineering solutions to the prevention of aircrew backache. However, for those aircrew required to operate old aircraft types alternatives to the rigid moulded lumbar support should be sought, particularly for the large proportion of helicopter pilots with backache who are currently without relief.

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Helicopter underwater escape and the initial responses to cold

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1. Summary

The initial responses to immersion in cold water represent one of the first major hazards to be faced by individuals in a ditched helicopter. The acceptance of this fact has led to the provision by some organisations of emergency underwater breathing aids (EUBA). In this paper two approaches to the provision of an EUBA have been examined - this goes some way to address the paucity of published work in this area.

2. Introduction

The initial responses to immersion in cold water are initiated by falling skin temperature, they have been given the generic title "cold shock", and include tachycardia, hypertension, an inspiratory "gasp" response and uncontrollable hyperventilation (1, 2).

For healthy individual it is the respiratory responses which probably represent the greatest danger, in particular the reduction in maximum breath hold time which occurs during sudden immersion in water at temperatures below 15°C (3). This can be particularly hazardous for individuals immersed in choppy water, or forcibly submerged in a sinking craft or ditched, inverted helicopter. Tipton et al (4) have reported that the maximum breath hold times of subjects, clothed in immersion dry suits, performing a simple simulated helicopter underwater escape in 10°C are remarkably similar, averaging (SD) 17.2 (3.7) seconds.

There is a reasonable chance that the crew and passengers of a ditched helicopter will have to perform an underwater escape; in 47% of Royal Navy helicopter accidents between 1972-1984 the helicopter sank or inverted immediately on ditching (5). Whilst it is impossible to make an accurate prediction about the time required to make a successful escape, estimations from groups such as the Coast Guard, the military, and civilian operators suggest that 40-60 seconds are required (4). It is the shortfall between the maximum breath hold time of individuals in cold water, and the time required to make an underwater escape from a helicopter, which provides the rationale for the provision of some form of EUBA.

Commercially available EUBA fall into two broad groups: "rebreathers" and self-contained underwater breathing apparatus (SCUBA). Examples of these two types of device include: the "Air Pocket" (AP) rebreathing bag and the "Short Term Air Supply System" (STASS) mini SCUBA set. The present experiment was undertaken to determine the performance of AP and STASS, during a simple simulated helicopter underwater escape.

3. Methods

EUBA: The AP includes an L-shaped, low profile 12 litre bag containing 2 circular perforated tubes to ensure the accessibility of the air exhaled into the bag. Attached to the bag is a 500cm length (unstretched) of flexible respiratory tubing, at the other end of which is a mouthpiece containing a simple valve for switching between breathing ambient air and rebreathing into the bag. The AP is provided with a noseclip which is attached to the mouthpiece assembly and is capable of being operated by one hand.

The STASS is a re-chargeable mini SCUBA set which is charged to a pressure of 3,200psi (220 bar) and provides approximately 50 litres of air through a single stage regulator and demand valve. The STASS contains a mouthpiece but is not provided with a noseclip.

Subjects & Design: The experimental protocol was approved by local ethics committees and all subjects gave their informed written consent to participate in the experiment. Young, healthy male subjects undertook simple simulated helicopter underwater escapes in water

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at 15°C and/or 5°C. Four subjects participated at both water temperatures, another four subjects participated at a single water temperature (2 at 5°C and 2 at 15°C). At each temperature the subjects used AP twice and STASS twice. Both the order in which the EUBA were used, and the water temperature in which the immersion took place, were counter-balanced. Before commencing the experiment the subjects were fully familiarised with the EUBA and experimental procedure during training runs in water at 30°C.

Procedure: On arrival at the laboratory the subjects had a 3-lead ECG attached to them. They were dressed in the Royal Navy winter sea helicopter aircrew equipment assembly comprising: long cotton underwear; aircrew socks; knitted inner coverall; immersion suit with integral AP; Mk15 flying coverall; lightweight aircrew boots; Mk25 lifejacket; Mk2 immersion gloves; and an air crew helmet.

The subjects were seated in a Shallow Water Egress Trainer (SWET), a structure constructed from tubular plastic and including a mock window and helicopter seat and seat harness. The SWET was positioned just above the surface of the water. After a five minute pre-immersion period, the subjects were instructed to perform a maximum exhalation followed by a large but not maximal inspiration. The volumes of these breaths were measured using a spirometer (Spiroflow, PK Morgan, Kent). Immediately upon completion of this manoeuvre the subjects began breath holding and inserted the mouthpiece of either the AP or STASS. In accordance with current operational procedures, a nose clip was worn with the AP but not with the STASS. Having initiated a breath hold, the subjects grasped the seat harness buckle with their right hand, and the frame of the mock window through which they had to exit with their left hand. The SWET was then immediately lowered and rotated into the water until it came to rest submerged and inverted. It took approximately 5 seconds from the initiation of breath holding to inversion in the water.

Once settled in the submerged inverted position, the subjects released their seat belt, egressed from the SWET and moved hand over hand backwards and forwards along a ladder placed at a depth of 1.25 m. The level of exercise undertaken underwater was standardised using an electronic metronome emitting pulses at a frequency of 48beats.min^{-1} via underwater speakers. At each pulse the subjects were instructed to move along one rung (40 cm) of the ladder. The subjects held their breath for as long as possible (BHTmax), they then used AP or STASS for as long as they felt comfortable so to do, or until one minute had elapsed from the commencement of breath holding. This time was one of the withdrawal criteria of the experiment, and was based on earlier work with AP (4).

Measurements: When using both breathing aids the subjects exhaled on surfacing. With AP the bag was sealed by the subjects before they came off the mouthpiece, and the sample of exhaled gas thus obtained was immediately analysed to determine its concentration of oxygen and carbon dioxide (Servomex 1400B, Servomex plc, Crowborough). Heart rate and ECG waveform were monitored continuously using a three lead telemetry ECG (Siemens, Erlangen, Germany).

The subjects signalled when they had broken their BHTmax by raising an arm. The oxygen extracted from the lung whilst performing the simulated simple underwater escapes was calculated for the experiments in which AP was used, from the change in oxygen concentration in the AP and lung volume at the start of the experiment.

Air consumption whilst using the STASS was measured by weighing the STASS bottle wet before and after the escape, an identical procedure was used (i.e. same amount of drying) to weigh the STASS on each occasion. The volume of air provided by STASS was established by emptying six units using a calibration syringe, the resulting average volume was 39.3l (BTPS) with a range of 32.7 to 47.9l.

Immediately following each submersion the subjects' evaluation of the device they had just used was obtained by asking them to appropriately mark three 10cm lines. The first of these referred to the ease with which the device could be used, and the extremes of the line were labelled: 0cm = very hard to use, 10cm = very easy to use. The second line referred to the comfort with which the device could be used, and the extremes of the line were labelled: 0cm = very uncomfortable to use, 10cm = very comfortable to use. The final line related to the confidence which the subject had in the device he had just used and was labelled: 0cm = had no confidence in the device, 10cm = had great confidence in the device. Any additional comments pertaining to the experiment made by the subjects were noted. After their last experimental run each subject was asked which device they preferred.

Statistical methods. As all the same subjects did not undertake immersions at 5°C and 15°C, separate analyses were undertaken according to the applicability of various mathematical models. The data obtained from subjects at a single temperature (either 5°C or 15°C) were analysed using a model which included linear additive terms for subject and condition (AP or STASS) effects. All effects in the model were considered as "fixed" rather than "random". The residuals are required to be normally distributed with variability not related to the levels of the variate of interest. Normality of residuals was achieved by transforming the raw data: the subjective data (ease, comfort, confidence) were converted to percentage values (based on distances along the 10 cm line) and an angular transform applied to these percentages.

4. Results

Unless stated otherwise, all results are quoted at the 5% level of significance. Five of the original eight subjects withdrew from the experiment and had to be replaced. It is important to note that at least three of these withdrawals were due to the inability of the subjects to use the EUBA in cold water. This was despite the fact that they had successfully completed the training and mock experimental runs in warm water.

15°C water: Six subjects provided data. No difference was found in the lung volume at which subjects commenced breath holding. BHTmax was significantly longer with AP (average 23.7s) than STASS (average 18.5s, SED of the means 1.4s). All 6 subjects completed 60s immersions with STASS, whilst 5 did with AP. The underwater times of the sixth subject were 53 and 54s on his two runs with AP, following BHTmax of 22 and 20s respectively.

All 3 subjective measures were significantly ($P<0.01$) higher with STASS compared to AP. The scales do not allow for the differences between the scores for the two EUBA to be described in quantitative terms. All subjects reported preferring STASS in this condition.

5°C water: Six subjects (four common to the 15°C condition) provided data. No difference was found in the lung volume at which subjects commenced breath holding. BHTmax did not differ between AP (average 21.3s) and STASS (average 19.7s, SED of the means 1.1s). Five of the 6 subjects completed 60s immersions with STASS, the underwater times of the sixth subject were 41 and 39s on his two runs, following a BHTmax of 19 and 23s respectively. Three subjects completed 60s immersions with AP, the other three had average underwater times/BHTmax of: 32s/18s; 41s/19s; 59s/17s. On a subject basis, immersion times with AP were less than those for STASS, with no subject having a longer immersion with AP than STASS.

All 3 subjective measures were significantly ($P<0.01$) higher with STASS compared to AP. All subjects reported preferring STASS in this condition.

The ECG during immersion was intermittent with some subjects and therefore difficult to analyse. An examination of R-R intervals revealed no significant differences between conditions two minutes before, or during, immersion. The average heart rates during the pre-immersion period were, 15°C: AP 93beat.min^{-1}; STASS 89beat.min^{-1}. 5°C: AP 91beat.min^{-1}; STASS 98beat.min^{-1}. The average heart rates during immersion were, 15°C: AP 93beat.min^{-1}; STASS 94beat.min^{-1}. 5°C: AP 89beat.min^{-1}; STASS 86beat.min^{-1}. As suggested by these rates, most of the subjects demonstrated a diving bradycardia (decreased heart rate) at some stage of their immersion.

5. Discussion

The results obtained with AP in the present investigation support those obtained in a similar earlier study (20) conducted in water at 10°C, with subjects wearing an immersion dry suit. Tipton and co-workers found that AP enabled five of their eight subjects to remain submerged for 60s and, when compared to an average maximum breath hold time of 17.2s, and at least doubled the underwater time of the other three subjects. In the present experiment, AP extended the underwater time of those four subjects who did not complete 60s submersions by a factor of 2.2 in comparison with BHTmax.

The high level of immersion protection provided by the aircrew clothing assembly in the present experiment is also evidenced by the longer average BHTmax observed in 5°C water in the present experiments compared to earlier work in warmer water (Ref. 4: Tw 10°C, BHTmax 17.2s; Ref. 6: Tw 11°C, BHTmax 15.6s;). Further evidence can be found in the comparatively low heart rates and oxygen extractions observed on immersion in the present, compared to earlier studies (3).

The level of protection provided for an individual, and the amount of work required during escape, are two of the most important factors determining both the absolute performance of EUBA and the comparative performance of devices based on a rebreather or SCUBA approach. As the level of clothing protection is reduced by the removal of clothing or water leakage, the amount of hyperventilation observed on immersion in cold water is increased (7). By definition ventilation increases disproportionately to oxygen consumption and, as a consequence, one would expect the performance of a SCUBA-based device to be more adversely affected than that of a rebreather. As workload increases, oxygen consumption increases in proportion to ventilation up to the point at which lactate accumulates in the blood and ventilation increases to a greater extent than oxygen consumption in order to buffer the falling pH of the blood. The accumulation of lactate does not occur until much higher work intensities than those required in the present investigation. As a consequence it can be concluded that any increase in the effort required to perform a helicopter underwater escape will have a similar effect on the duration provided by rebreather and SCUBA-based devices.

In the present experiment both AP and STASS enabled the majority of subjects to remain immersed for 60 seconds. It is clear, however, that this time was achieved more easily with STASS than AP. This conclusion is based on, i) the subjective responses obtained following the experimental runs which, although acceptable with both devices, were better with STASS ii) the volumes of air used with STASS iii) the oxygen concentrations in AP at the end of the experiment. With STASS, an average of 48% of the air available was used during the 5°C immersions and 35% during the immersions in water at 15°C. In theory therefore, in the conditions of the present experiment, the subjects could have remained underwater for an average of 2-3 times longer than they actually did, particularly if one remembers that, unlike with AP, it would be possible to breath hold as the STASS became exhausted.

In contrast, the gas concentration data obtained from AP suggest that this device was nearer to its limit of usefulness. Some subjects reported an increase in breathing frequency towards the end of the runs with AP. The critical alveolar PO2 (PAO2) for hypoxic loss of consciousness in healthy people ventilating normally has been reported to be between 4.00kPa (30mmHg) and 5.07kPa (38mmHg). The time spent at a given PAO2 is clearly critical, and this is recognised by including a time factor in the calculation of the "dose" of hypoxia received. Thus, a dose of 20kPa.sec (150mmHg.sec) of hypoxia is thought to be required to induce loss of consciousness (2-4, 9), and a PAO2 of 4kPa (30mmHg) would therefore be predicted to result in loss of consciousness in about 5 seconds. In the present study, the average oxygen concentration in AP of those subjects who completed the one minute immersion was 7.69kPa (57.7mmHg) across conditions, with one subject falling to 4.9kPa (36.8mmHg). The corresponding average figure for carbon dioxide was 6.56kPa (49.2mmHg). The rates of reduction of oxygen concentration seen in AP in the present study enable an estimated average time to a PAO2 of 5.07kPa (38mmHg) of 75 seconds to be estimated. This duration would be extended if a larger breath were taken initially. For example, in the conditions of the present study, the time to a PAO2 of 5.07kPa (38mmHg) would be extended to approximately 90s if the average volume of the breath inhaled prior to breath holding had been increased by 1 litre. These figures ignore the small increase in the partial pressure of oxygen associated with increased pressure at depth.

The subjects who failed to complete a 60 second immersion (1 in the 15°C; 3 in 5°C condition) with AP had higher oxygen concentrations (average 11kPa [82.5mmHg]), and lower carbon dioxide concentrations (5.79kPa [43.4mmHg]) in AP at the end of their immersions than those subjects completing 60 second immersions. This suggests that either these subjects stopped for reasons other than those related to the gas concentrations in AP, or that they were more sensitive to the changes in gas concentrations on a particular day. They were not generally more sensitive to hypoxia or hypercapnia than other subjects, as they tolerated lower levels of oxygen and higher levels of carbon dioxide in the runs in which they managed to remain immersed for 60 seconds. The answer probably lies in the fact that when these subjects failed to complete a 60 second immersion they were generally either undertaking their first or second run with AP. In spite of the training programme given to subjects in the present study, air utilisation from STASS, and oxygen extraction from AP, tended to be lower in later compared to earlier exposures. This is regarded as an indication that they were becoming more comfortable with, and efficient at, the task in hand. The subject who did not complete any 60 second immersions with AP or STASS in water at 5°C did so because of cold-induced pain on his face and head.

The present experiments demonstrate that the performance with both devices is significantly improved by in-water training. This is primarily because it gives the opportunity for individuals to get used to the combined stresses of using a new piece of equipment and performing a helicopter underwater escape. The training sessions were also useful for identifying those subjects who could not use STASS without a noseclip. A total of four subjects were unable to use STASS without being provided with a noseclip.

In contrast to ease of use during the experiments, it was relatively easier to train subjects with AP compared to STASS. Three of the subjects reported finding AP easier to use during the training runs, the rest of the subjects did not express a preference.

In choosing an EUBA it is clearly critical to determine the performance objectives (e.g. underwater time) required for the user population (e.g. aircrew or passengers) in the potential conditions in which the device may have to be used. Once the performance of an EUBA is considered adequate, the final decision about whether or not to use it will depend on many other factors including: cost; training requirements and maintenance needs. As there is a risk of a pulmonary overpressure accident occurring with a SCUBA device, it is probable that the cost of in-water training will be greater for this device than for a rebreather. The costs and logistics associated with maintaining SCUBA devices are also likely to be greater than those for rebreathers.

Finally, three points are worth noting. Firstly, subjective responses, photographic and video evidence from the present work support earlier recommendations (8, 9) for consideration to be given to the provision of goggles to assist in underwater escape. Secondly, it must be remembered that the data obtained in the present experiments, and the conclusions which follow, are specific to the circumstances (clothing etc.) examined and are already biased by the fact that they were obtained from subjects who were prepared to undertake the experiment.

Three subjects withdrew from the experiment because they found it too onerous. As such, it should be noted that there will be some individuals who will, inevitably, struggle to perform underwater escapes irrespective of the equipment they are given.

It is concluded that both AP and STASS can significantly extend the underwater survival time of individuals when compared to their BHTmax. In conditions similar to those of the present experiment (simple escape, good thermal protection, good visibility) STASS will give a longer duration than AP, but AP will extend underwater survival time by a factor of 2-3 when compared with maximum breath hold time. Irrespective of the EUBA provided, in-water training will significantly improve the ability of an individual to use it.

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U.S. Naval and Marine Corps Helicopter Mishap Trends: Over Water Mishaps (1985 – 1997)

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Abstract

U.S. Navy and Marine Corps helicopter mishaps, occurring over water, were examined under the Naval Air Systems Command sponsored Advanced Crashworthy Aircrew Survival Systems (ACASS) Program. The charter of the ACASS program is to increase levels of safety and survivability for aircrew and passengers involved in mishaps. Problems concerning airframe crashworthiness and mishap victim survivability during and after a crash were identified through the study of data provided by the United States Naval Safety Center. Studying mishap data provides a key starting point towards improvement of airframe crashworthiness and allows justifying what types of new and emerging technologies should be chosen to improve safety and to lessen occurrences of injury among mishap victims. For the purpose of this study, over water mishaps involving AH-1, UH-1, H-46, H-53, and H-60 helicopters were examined between the time period of 1 October 1985 through 30 September 1997. Findings will be used to support continued U.S. Navy research in areas of airframe safety, occupant seating and restraint, post-crash survivability, and improving survival equipment.

Introduction

U.S. Navy and Marine Corps helicopter mishaps occurring over water have recorded a number of unique problems when considering airframe crashworthiness and the survival of passengers and aircrew. Under the Naval Air Systems Command sponsored Advanced Crashworthy Aircrew Survival Systems (ACASS) Program, mishaps were studied that involved AH-1, UH-1, H-46, H-53, and H-60 helicopters. In total, 64 survivable and non-survivable Class A over water mishaps occurred throughout these helicopter communities between 1 October 1985 through 30 September 1997. A Class A mishap is defined by the Naval Safety Center as a mishap in which the total cost of property damage (including all aircraft damage) is $1M or greater; or in which any fatality or permanent total disability occurs with direct involvement of a Naval/Marine aircraft.[1]

Navy and Marine Corps Survivable & Non-survivable Class A Helicopter Mishaps

All helicopter Class A over water mishaps occurring within a 13 year period were divided into distinct and significant categories. Accidents having occurred within specific helicopter communities (Figure 1) were first examined. Accidents in each community were then examined and classified as to having been survivable or non-survivable (Table I and Figure 2). Finally, those accidents that were survivable were studied to determine what types of problems were forced on victims during impact, egress, and survival phases of each mishap. A survivable mishap is defined as a mishap in which the forces transmitted to the occupant through the seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations, and in which the structure in the occupants immediate environment remains substantially intact to the extent that a livable volume is provided for the occupant throughout the crash sequence[2].

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[1] Chief of Naval Operations Instruction 3750.6Q, CH1. March 27, 1991; pp. 4-8, para. 413

[2] Desjardins, S.P. *et. al*, "Aircraft Crash Survival Design Guide, "USAAVSCOM TR-89-D-22, Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity (AVSCOM), Fort Eustis, VA, December 1989.

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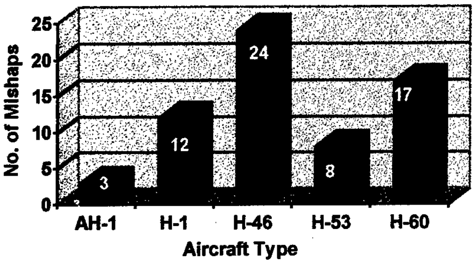

Figure 1- Over Water Mishaps (1985-1997)

	AH-1	H-1	H-46	H-53	H-60
Class A Over Water Mishaps	3	12	24	8	17
Survivable	2	9	21	4	15
Non-survivable	1	3	3	4	2
Day Mishaps Sur/Non-Sur	1/0	6/0	12/2	3/3	9/0
Night Mishaps Sur/Non-Sur	1/1	3/3	9/1	1/1	6/2

Table I - Platform Data (1985-1997)
Survivable and Non-Survivable Mishaps

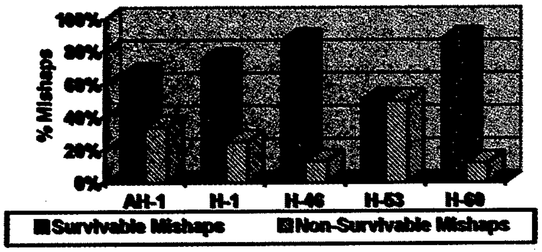

Figure 2 - Percentage of Survivable vs. Non-Survivable Class A Over Water Mishaps (1985-1997)

As depicted in Figure 1, the H-46 and H-60 recorded the highest number of over water mishaps between 1985 and 1997. Of particular concern is the fact that the H-46 is a troop carrying aircraft operated by the U.S. Marine Corps. In survivable mishaps alone, there were more over water mishap victims associated with the H-46 than all other platforms combined (see table III). This is unique from the standpoint that the majority of victims were passengers, not aircrewmen as was the case in the other helicopter communities. Those individuals did not receive the same types of training for helicopter egress and water survival which is required for aircrew. Survivable mishaps were then given the highest consideration because they were examined to determine why individuals aboard some mishap aircraft were injured or killed while others were not. Crashworthy/airframe safety features and problems encountered by mishap survivors for each each helicopter community is discussed under *Survivable Class A Mishaps: Aircraft Description and Survival Issues.*

Causal Factors and Survival Rates For All Over Water Mishaps

For the platforms studied, mechanical/maintenance problems caused 44 percent of survivable and non-survivable Class A mishaps between 1985 and 1997. The remaining 56 percent were attributed to non-mechanical/maintenance reasons, such as loss of situation awareness, disorientation in the cockpit, or cockpit resource management (see Table II). Of a total 370 pilots, aircrew, and passengers, 217 survived Class A mishaps for the five platforms studied. This reflects an overall 59 percent victim survival rate for all over water mishaps occurring in the five platforms during the time period. The mishap victim survival rate is a direct quotient: mishap survivors divided by the total population of *survivable and non-survivable* mishap victims. Figure 3 further clarifies aircraft type and survival rates for all over water mishaps and for survivable over water mishaps. With many crashworthy features designed into the airframe, seating, and fuel system, the H-60 helicopter recorded the highest overall survivability rate (82%). The H-53 helicopter, a much larger troop and cargo carrying aircraft than the H-60, recorded the lowest over water survival rate (25%) for the 13-year period.

	AH-1	H-1	H-46*	H-53	H-60**
Mishaps Caused by Mechanical Problems	0	5	10	4	7
Mishaps Caused by Non-Mechanical Factors	3	7	12	4	9

* One mishap undetermined and one mishap supervisory in error. These two mishaps are not reflected in Table II.

** One mishap undetermined. This mishap is not reflected in Table II.

Table II. Causal Factors for Over Water Class A Mishaps, (1985-1997)

	AH-1	H-1	H-46	H-53	H-60
Total Population of Over-water Mishap Victims (Survivable & Non-survivable Accidents)	6	50	191	59	64
Population of Over-water Survivable Mishap Victims	4	35	177	20	57
Number of Day Mishap Survivors/Non-survivors	2/0	20/6	76/17	15/0	31/7
Number of Night Mishap Survivors/Non-survivors	1/1	7/2	49/35	0/5	16/3
Survival Rate Among Over-water Survivable Mishap Victims (%)	75%	77%	71%	75%	82%
Day Mishap Survival Rate (%)	100%	77%	82%	100%	82%
Night Mishap Survival Rate (%)	50%	78%	58%	0%	84%
Number of Survivors Deploying Life Rafts (% of survivors)	0	7 (26%)	23 (18%)	0	8 (17%)

Table III – Crash Site Data

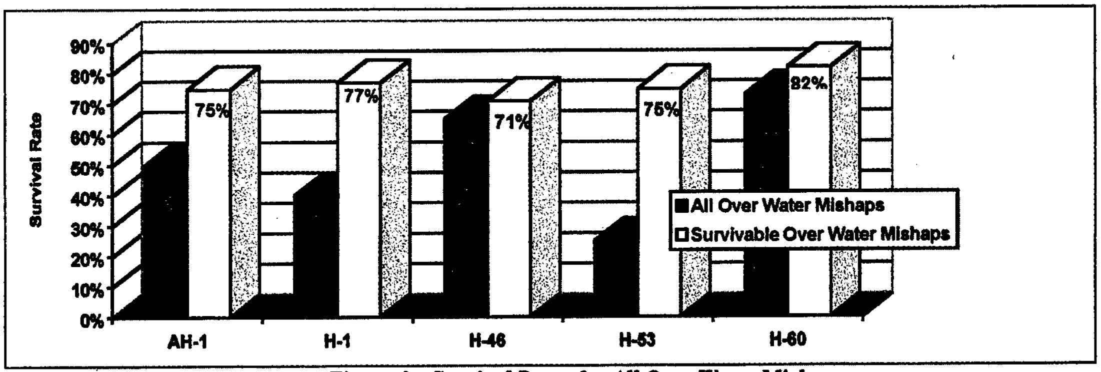

Figure 3 - Survival Rates for All Over Water Mishaps
vs.
Over Water Survivable Mishaps (1985-1997)

Survivable Class A Mishaps: Aircraft Description and Survival Issues

Mishap victim survival rates and survival concerns for *survivable* helicopter Class A mishaps is presented in this section. When the population in *survivable* mishaps was exclusively considered, it was discovered that the overall survivability rate for the five platforms increased to 74 percent. The highest survival rate associated with *survivable* mishaps occurred, once again, in the SH-60. Survival rates associated with platforms capable of carrying passengers and troops (the H-46, H-53 and H-60) were very close to one another: between 71 and 77%. Finally, the figures on the AH-1 Cobra helicopter are not significant because there were only three over water class A mishaps....two of which were survivable. The entire mishap victim population for Cobra over water mishaps numbered six.

AH-1

The AH-1, developed and manufactured by Bell Helicopters, was originally introduced into military service and used extensively in Vietnam as a fire support vehicle. The version currently in service with the Marine Corps is the twin engine, "W" version. As a fire support vehicle it is equipped with a 20mm M197 gun in the nose turret, and can carry 2.75" and 5.0 rockets, Hellfire and TOW anti-armor missiles, sidewinder air-to-air missiles, and sidewinder anti-radiation missiles. The engine/transmission, seating, and miscellaneous equipment can withstand crash impact forces of 15 G's[3] along all axes. It is equipped with a four-point restraint system and non-crash attenuating seats.

As previously mentioned, between 1985 to 1997, three over water Class A mishaps occurred: two of those mishaps were survivable (see Table 1). The population involved in *survivable* mishaps was very thin, and subsequently no conclusions can be drawn concerning significant survival issues or differences between day and night mishap survivability rates. When viewing the two *survivable* mishaps, however, it was noted that survivors never deployed life rafts during the post egress phases of mishaps (Table III). Also, prior to egressing their aircraft, all survivors were rendered either dazed or unconscious at the time of impact and were forced to escape the airframe under water.

H-1

The H-1, developed and manufactured by Bell Helicopters, was originally introduced into military service in 1962 and was used extensively in Vietnam for ambulance, gunship, combat rescue, and utility services. The version currently in service with the Navy and Marine Corps is the twin engine, "N" version utilized in a variety of roles. As an amphibious assault support vehicle it is capable of transporting 8-10 combat loaded Marines and/or supplies. In the ambulance role, it is capable of transporting six litter patients and one attendant. In the fire support role it can be armed with 7.62 M-60 machine guns, GAU-2B/A machine guns, 50 caliber machine guns and 2.75'' rockets in a variety of mixes. The H-1 airframe is equipped with four-point restraint, non-crash attenuating pilot seats which can withstand crash impact forces of 13.6 G's along all axes. The airframe engine/transmission retention is rated at 8 Gs along all axes. The aircraft is equipped with two point lap belt restraint, non-crash attenuating aircrew and passenger seats rated at 8Gx, 10Gz, and 7.2 Gy. Two variants of aircraft were reviewed for this report, the UH-1N and HH-1N.

Eight over water survivable mishaps occurred between 1985 and 1997. For the period studied, the UH-1N recorded the highest percentage of individuals lost at sea in *survivable* over water mishaps: a little over one-fifth the pilots *and* aircrewmen/passengers were never recovered (see Table IV). There was no significant difference when comparing survival rates between day and night conditions. When viewing the eight *over water survivable* mishaps, only 7 of the 27 (26%) mishap survivors deployed life rafts during egress phases of mishaps (Table III).

	AH-1	H-1	H-46	H-53	H-60
Mishap Victims that Drowned	0	1	15	0	4
Mishap Victims Lost at Sea	1	7	31	4	3

Table IV - Mishap Victims Drowned, Mishap Victims Lost at Sea in Survivable Mishaps (1985 – 1997)

H-46

The H-46 was originally designed as a medium lift, cargo and troop transport vehicle. Three variants of aircraft have been developed; two are flown today, the CH-46D and CH-46E. The aircraft can accommodate 25 passengers or 15 litters with two medical attendants, or 10,000 pounds of cargo externally in a sling below the fuselage.

The CH-46E is operated by the U.S. Marine Corps, transporting troops and personnel ashore during an

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[3] G-forces are normally expressed along the x, z, y axes. Gx is the G-force along the longitudinal axis of the aircraft. Gz is the G-force along the vertical axis of the aircraft. Gy is the G-force along the lateral axis to the aircraft.

amphibious assault, or from one area of the beachhead to another during shore operations. The CH-46E employs some crashworthy airframe features. The engine/transmission can withstand crash impact forces of 20 Gx, 20 Gz, and 10 Gy and has Variable Load Energy Absorbing (VLEA) pilot and copilot seats rated at 30Gx, 30 Gz, and 15 Gy. The CH-46D is primarily operated by the U.S. Navy for carrying troops and cargo. It is operated over water, performing the vertical onboard replenishment missions. The CH-46D, engine/transmission can withstand crash impact forces of 20 Gx, 20 Gz, and 10 Gy. The pilot and copilot seating is non-crash attenuating, only capable of withstanding the same forces as the airframe. Both variants of aircraft are furnished with two point lap belt restraint, non-crash attenuating aircrew and passenger tube and fabric seats that are rated at 8 Gx, 8 Gz, and 3 Gy.

Twenty-four *survivable* mishaps occurred between 1985 and 1997 (see Table I). Over the period studied, the H-46 recorded the highest number of mishap victims involved in *survivable* mishaps as having drowned. Also, this platform recorded and the highest number (second highest percentage) of individuals lost at sea: 5 pilots (14%) and 26 aircrewmen/passengers (22%) were lost at sea and 15 aircrewmen/passengers drowned (see Table IV). Only the UH-1N recorded a higher percentage of mishap victims lost at sea during *survivable* crashes. Speculation as to why mishap victims were lost at sea, especially passengers, rest on the of lack of dedicated egress training, passengers not having received training and not being issued emergency supplemental breathing devices, and inadequate equipment and airframe design not allowing mishap victims to locate escape routes and emergency exits.

As far as survival rates are concerned, for survivable mishaps there was some difference when comparing survival rates between day and night survivable over water crashes (82% during day and 58% during night.) Finally, only 23 out of 125 (18%) mishap survivors deployed life rafts during egress phases of mishaps (Table III).

H-53

H-53D

The CH-53A was developed by Sikorsky Aircraft in the mid-1960's as a twin turbine, all weather, heavy lift/troop transport helicopter. The CH-53D, an improved version of the CH-53A, was delivered to the Marine Corps between 1969 and 1972. The RH-53D, originally developed for Airborne Mine Countermeasures, has been transferred to Marine Corps Reserve squadrons. The CH-53A/D and RH-53D engine/transmission can withstand crash impact forces of 20Gx, 20Gz, and 10Gy while maintaining sufficient structural integrity to protect its occupants. The pilot and copilot seats were designed to MIL-S-7832A to remain intact and be retained within the airframe up to impact forces of 18Gx, 13Gz, 10Gy. As a result of Airframe Change 321, the H-53D series has been equipped with improved, crashworthy, energy absorbing (EA) seats in the cockpit, capable of withstanding impact forces of 30Gx, 30Gz, and 15Gy. The crew and troop seats conform to MIL-S-85510, are a two lap belt restraint, non-crash attenuating tube and fabric design, and are capable of withstanding impact forces of 8Gx, 8Gz, and 3Gy.

H-53E

The MH-53E and CH-53E were developed in the mid-1970's and procured under an Engineering Change Proposal as an upgrade to the CH-53A/D. The H-53E has a number of significant differences from its predecessors and in reality is an entirely different aircraft. The H-53E has a longer fuselage, a third engine, a seven-bladed main rotor system, an uprated transmission, and it has a crashworthy fuel system (MIL-T-27422). The aircraft can carry 55 personnel in addition to its crew of four. As a part of design features on newer H-53Es or as a result of Airframe Change 321 for older H-53Es, the aircraft has been equipped with improved, crashworthy, energy absorbing (EA) seats in the cockpit, capable of withstanding impact forces of 30Gx, 30Gz, and 15Gy. The crew and troop seats conform to MIL-S-85510, consist of a two lap belt restraint, non-crash attenuating tube and fabric design, and are capable of withstanding impact forces of 8Gx, 8Gz, and 3Gy.

Four over water *survivable* mishaps involving H-53D and H-53E airframes, occurred between 1985 and 1997 (Table I). When comparing day to night survival rates for survivable mishaps, the data is not meaningful due to the small population of mishap victims. When viewing the four over water survivable mishaps, rafts were never deployed from any mishap aircraft (Table III).

H-60

The H-60 was developed by Sikorsky Aircraft and first introduced into the U. S. Navy in 1985 as the SH-60B LAMPS MK-III. Subsequently, the SH-60F CV Anti-Submarine Warfare helicopter and the HH-60H Combat Search and Rescue (CSAR)/Light Attack and the VH-60N Personnel Transport have entered service. Current plans call for introduction of the SH-60R and CH-60 into the fleet. Since its inception, the H60 has incorporated numerous crashworthy design features including energy absorbing seats, crashworthy fuel systems and improved retention of high mass components. The engine/transmission can withstand crash impact forces of 20 Gx, 20 Gz, and 10 Gy. It is equipped with five point restraint, crash attenuating pilot and aircrew seats capable of withstanding impact forces of 35 Gx, 20 Gz, and 20 Gy, and four point restraint, crash attenuating passenger seats that are rated at 30 Gx, 20 Gz, and 20 Gy. Seat crashworthiness, however, is compromised by airframe floor anchor strength, rated at 20 Gx, 20 Gz, and 10 Gy.

Fifteen *survivable* mishaps occurred between 1985 and 1995 (Table I). Survivability rates when comparing day and night mishaps varied by only a few percentage points, 82% and 84% respectively. When viewing these over water survivable mishaps, eight out of 47 (17%) mishap survivors deployed life rafts (Table III).

Discussion and Recommendations

Several major issues stand out regarding the information presented in this paper: mishap survivor percentages; the deployment of life rafts, and the number of mishap victims who had drowned or were lost at sea in H-1 and H-46 survivable mishaps. Each one of these issues warrant a certain amount of discussion.

The goal of the Navy's Advanced Crashworthy Aircrew Survival Systems program is to bring mishap victim survival percentages for helicopter mishaps up to a level experienced by tactical fixed wing communities, that number is over 80%. Between 1985 and 1997, the overall 74% survivability rate for *survivable* over water helicopter Class A mishaps for those platforms studied seems within striking distance of the TACAIR survival percentages, but it will still take some time to reach the ACASS program goal. Issues concerning more effective methods of egress, and improving emergency hatch design (especially for the H-46 helicopter) need to be focused upon. Incorporating crash attenuating seating in all platforms, and improving restraint (this includes inertia reels and possibly airbags) in pilot and aft cabin crew stations should also be taken into consideration for preventing incapacitating injuries which might hamper or prevent egress (subsequently, the mishap victim could drown). If these areas are addressed, then improvement of mishap victim survivability rates could show promise.

Current restraint configurations for troops and passengers sitting in non-crash attenuating, tube and fabric crew seats in most Navy and Marine helicopters is appalling. Impact, G-forces, and contact with the interior of an aircraft have all been cited as primary injury mechanisms during *survivable* over water Class A mishaps. As a recommendation, crash attenuating seats should be installed in all H-1, H-46, and H-53 troop/passenger crew stations, and the development of a body harness type restraint system with inertia reels should be put in place. Current four and five point restraint systems in pilot compartments require restraint straps be draped over flight jackets, survival vests, emergency radios, HEED bottles, and personal equipment. This type of arrangement creates inadequate and ill fitting restraints. It allows for movement (play) between the seat occupant and restraint straps during the impact phase of a mishap. A body harness shows a possible method towards solving this problem because it is donned under clothing and equipment, and movement under restraint straps would be held to a minimum. Also, there are no helicopters in the Navy and Marine Corps today that are equipped with inertia reels which are qualified, none that are used are on the Qualified Products List (QPL). Current inertia reels are known to be defective as a result government and independent testing. It is highly recommended that each aircraft maintaining authority review this situation and force retrofit their respective platforms with reels that have been qualified and have been placed on the QPL. Finally, an improvement in mobile restraint for aircrewmen is needed. Aircrewmen need to move about aft cabin sections of helicopters in order to perform normal flight duties. A mobile restraint system, similar to the type of equipment installed in U.S. Army Black Hawks should be considered. That type of restraint system offers a rapid locking feature which utilizes a number of seat mounted inertia reels. It would provide better protection than exists today in a gunner's belt type restraint.

The data concerning deployment of life rafts by mishap survivors points towards a dangerous and unsettling situation. Two of the five helicopter communities examined never recorded any deployment of a life raft during mishaps. Between 1985 through 1997, for the five platforms studied, only 37 out of 217 (17%) over water mishap survivors deployed life rafts. Poor stowage and accessibility locations for life rafts within respective platforms, heavy weight and bulkiness of the equipment, and mishap survivors fighting the clock to exit a platform filling with water and turning upside down are the main reasons why life rafts are seldom deployed. What is most needed for multi-person life raft access and deployment are airframe external mounting arrangements. Automatic deployment of life rafts for large passenger/troop carrying helicopters could be easily accomplished if rafts were mounted and released from external hard points or from select weapon stations at the time of impact. Also, manual release by pilots/aircrew could be accomplished if the situation so warranted. As a recommendation, new technologies focusing on lighter, stronger, more resilient materials made from weaves developed in the 1990's need to be exploited for raft construction. Materials allowing for seamless welds and the joining of materials need to be developed/procured, thus allowing for weight and packing volume reduction. Lighter, new technology materials and vacuum packing would aid in the external mounting of rafts if external storage and restricted space requirements presented major airframe redesign considerations.

Clearly, the high number of drowning and individuals lost at sea in the H-46 community needs to be focused upon. Egress and water survival training is probably the single most important factor influencing the successful outcome of an over water mishap for pilots and aircrewmen. Refresher training should be mandatory at least once a year for aircrew, and should also be considered prior to H-46 or other helicopter community squadrons deploying to sea. Also, an active program to train troops and passengers should be aggressively pursued. Passengers involved in H-46 *survivable* over water mishaps have accounted for the greatest number of victims having drowned or never having been recovered in *survivable* mishaps. It is recommended that a highly mobile and portable training device developed by the Canadians be considered to train troops and passengers. This device, known as the Modular Egress Training Simulator (METS) is capable of training passengers, troops, and aircrew to become familiar with hatch release mechanisms and platform escape when involved in over water mishaps, and it is reconfigurable to emulate a variety of platform types. The Canadian Armed Forces trains in the METS and has proven its worth in lives saved. Finally, improvement of emergency escape hatch design should be actively pursued. Installation of emergency lighting on handles and release mechanisms that are a part of emergency escape hatches would allow an easier means of egressing a submerged and sinking aircraft, and would insure a better chance for aircrew survival should an over water mishap occur.

BIOGRAPHIES

RaNae Contarino is presently the Advanced Crashworthy Aircrew Survival Systems Program Manager at the Naval Air Warfare Center Aircraft Division in Patuxent River, MD. Her experience has been primarily in the test and evaluation of life support systems

George F. Loeslein is employed at the Naval Air Warfare Center, Aircraft Division in Patuxent River, MD as a member of the Integrated Test Team for the V-22 Osprey. After gaining his Engineering, degree from North Carolina State University he served as a U. S. Naval aviator. He has twenty-five years of experience in aircraft/systems, training and maintenance programs. He has participated in, and managed, programs involving organizational and intermediate level maintenance supervision, system safety, aircrew training and ground/flight procedures. Mr. Loeslein retired from the U.S. Navy after 22 years as a helicopter and fixed wing aviator.

Lawrence E. Kinker is presently responsible for systems technology at Flight Dynamics and Safety Inc. His B.S. degree in Chemistry is from the University of Missouri (Columbia). His experience has been primarily in the test and evaluation of escape system decision; live subject testing on the Naval Air Warfare Center, Aircraft Division, Warminster ejection tower; and field investigations among pilots and aircrew who operate fixed and rotary wing aircraft. In addition, Mr. Kinker was a U.S. Navy Active and Fleet Reserve helicopter pilot for 20 years.

Helicopter Flight Accidents in the German Federal Armed Forces in the last 15 years

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Summary:

This presentation deals with flight accidents made with helicopters of the Bundeswehr in the period of 1 January 1984 until today. Given a total rate of 0.22 accidents per 10.000 hours, that is 48 accidents in a total of 2.2 million hours, the number of flight accidents can be stated as low; 47 persons were killed and 48 helicopters destroyed.
The intensive efforts invested in flight safety within the Bundeswehr are successful. The same applies to the intensive and continuous aeromedical care and control of flying personnel, which are ensured centrally by the Air Force Institute of Aviation Medicine and locally in the flying units and during operations by well trained and experienced flight surgeons. The flight accident rate will probably improve even more if Crew Coordination and Management concepts are implemented and further developed. For this, however, efforts must be made to increase the acceptance of these concepts particularly among senior flying personnel.

A closer look at the helicopter flight accidents situation shows that most of the accidents are due to two flight physiological phenomena: spatial disorientation and empty field myopia.

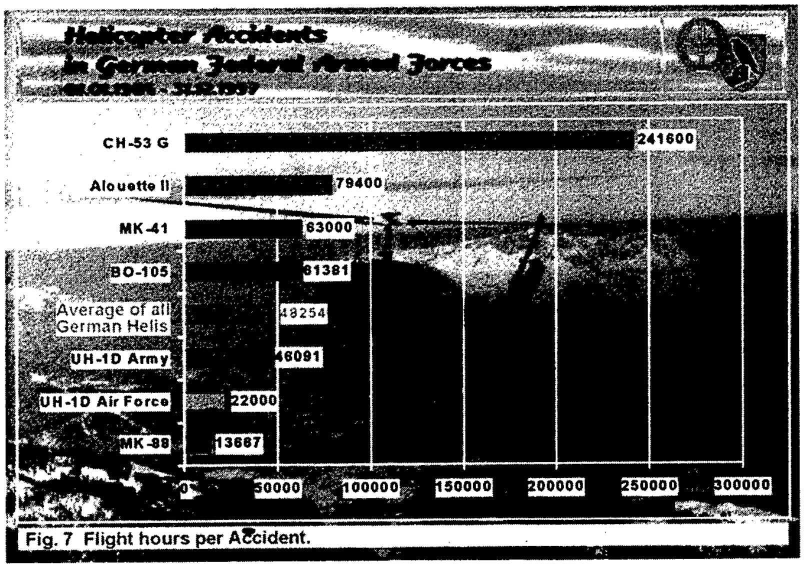
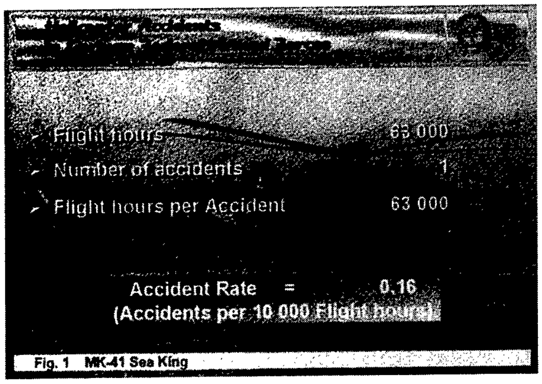


Fig. 7 Flight hours per Accident.

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

Special consideration will be granted to the aerodynamic peculiarities of a hingeless rotor system, the knowledge and respect of which will help to prevent accidents especially when flying in a low-altitude profile.

During my presentation, I would like to inform you about flight accidents made with helicopters of the Bundeswehr in the period of 1 January 1984 to 31 December 1997. The current year only saw one very serious accident. Though this accident is not contained within the compiled data, I will discuss the accident in detail during my comments.

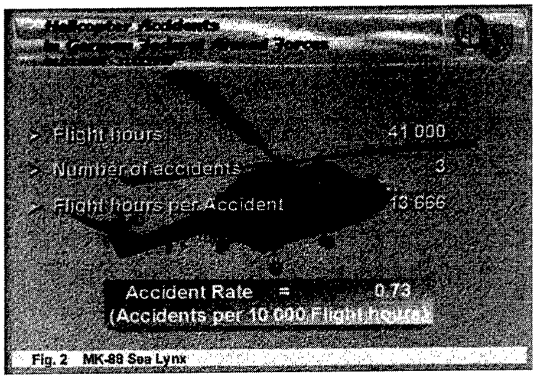

- Flight hours 63 000
- Number of accidents 1
- Flight hours per Accident 63 000

Accident Rate = 0.16
(Accidents per 10 000 Flight hours)

Fig. 1 MK-41 Sea King

Let me start with the Navy's MK 48 Sea King, a helicopter type that caused only one accident during the period concerned without involving casualties. In the last 10 years, this helicopter type has flown without any accident. This is all the more remarkable since the Sea King is employed in both the military SAR service and the civil medical air rescue service. This means that the helicopter crew must execute missions under the most difficult weather and environmental conditions causing high psychological and physiological pressure. An important point for this absence of accidents seems to be that the four-crew members of the MK 48 can rely on a highly advanced Crew Coordination Concept, which is always being further developed. In addition, the personnel flying these missions are very limited and joined in one single unit, allowing the crews to work together in thorough coordination and to standardize the operational procedures to a high degree.

Things are different, however, with the MK 88 Sea Lynx, which is employed as a shipboard helicopter on Navy frigates. In this case, three flight accidents during a total of only 41000 flight hours were enough to raise the flight accident rate to 0.73, that is, one accident for every 13666 hours flown. For the period considered, this is the highest accident rate of all Bundeswehr helicopter types. Two of these accidents occurred during the training of emergency procedures, another during a mission, which is normally unusual for this type of helicopter, namely during a medical evacuation flight at night. In this last case a high psychological load due to the unusual transport of a life-threatened patient in poor weather conditions added up to little experience of the crew both in terms of flying skills and in this type of mission, and finally the insufficient Crew Coordination. Therefore, two persons were killed and three slightly wounded. One of the dead was the patient who normally should have been saved.

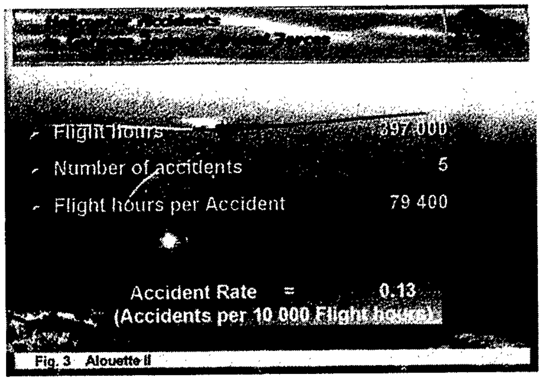

Helicopter Accidents

- Flight hours 41 000
- Number of accidents 3
- Flight hours per Accident 13 666

Accident Rate = 0.73
(Accidents per 10 000 Flight hours)

Fig. 2 MK-88 Sea Lynx

In the following I will present to you those helicopter types which are flown exclusively in the Army Aviation Branch. The Alouette II, which will be phased out definitely in the next few years, caused five accidents in the period considered. During these accidents six aircraft were destroyed two persons killed and 11 wounded. Up until now the Alouette II has been the basic training helicopter of the Army Aviation School. Except for a few aircraft pilots which were and are still being trained at Fort Rucker within the framework of the Euro-NATO-Training program, all Army Aviation helicopter pilots have received their basic training on this helicopter type. In the past, before it was increasingly being replaced by the more modern BO 105, the Alouette II was employed within the Army as a liaison helicopter, too. Only two accidents happened during operational flight, the three other accidents during basic training and within the framework of the Combat Training Program. In one case, the aerophysiological phenomenon "empty field myopia" caused the aircraft to encounter the ground, which was entirely covered with snow, causing the aircraft to roll over. The two other accidents were attributed, at least in part, to insufficient Crew Coordination.

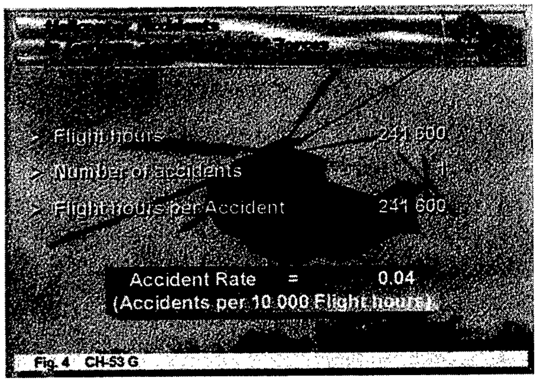


- Flight hours 397 000
- Number of accidents 5
- Flight hours per Accident 79 400

Accident Rate = 0.13
(Accidents per 10 000 Flight hours)

Fig. 3 Alouette II

As far as the CH 53 is concerned, a remarkable result can be reported. In the time considered, that is, during 241.600 hours, only one accident happened. With the ensuing flight accident rate of 0.04, this type was the most reliable rotary aircraft of the Army Aviation Branch and the Bundeswehr as a whole. The reason for this result is, to my mind, to be found in the Crew Resource Management which the four-crew members of the CH 53 apply even if it is maybe not consciously established. In addition, up to now only senior and experienced pilots were trained on this type, which resulted in a high degree of experience. The extent to which the significant introduction of younger staff, which is now in view, will affect flight safety can not be said by now. Our CH 53 crews also have the longest experience in Army Aviation missions abroad. For more than 5 years they were employed in Iraq to transport UN inspectors and for meanwhile 2 $^1/_2$ years they have flown missions in the former Yugoslavia, both missions without any accident.



- Flight hours 241 600
- Number of accidents 1
- Flight hours per Accident 241 600

Accident Rate = 0.04
(Accidents per 10 000 Flight hours)

Fig. 4 CH-53 G

Before I refer in detail to flight accidents caused by the BO 105, I would like to draw your attention to some peculiarities of this weapon system. The BO 105 is fitted with a hingeless rotor system, that is, the rotor system's blades are connected directly to the rotor head, however, their material is so flexible that it replaces the function of mechanical flapping hinges. These "virtual" hinges are situated far away from the center of the rotor head, which increases the system's ability to transfer **torque**. Therefore, the rotor system's steering response is extremely high. In fact, this helicopter type allows adopting any flight attitude and, if the pilot only reacts quickly enough and, above all, at a sufficiently high altitude, to return to the initial flight attitude. The high steering response can be best understood when comparing the times passing between the activation of the controls and the reaction of the aircraft. A Jet Ranger, for example, needs 1.7 sec to react, a Gazelle helicopter 1.2 sec and the BO 105 only two tenths ($^2/_{10}$) of a second. In this context I would also like to point out that the EC 135 and the TIGER will be as performant in terms of steering response as the BO 105, because they are also equipped with a hingeless rotor system. An other peculiarity of the BO is that it can be controlled even at -6 G. In the negative G range the Bell UH1-D can no longer be controlled at all, and the Gazelle is uncontrollable when it exceeds -0.6 G. In practice, this means that the BO pilot could fly a forward controlled loop.

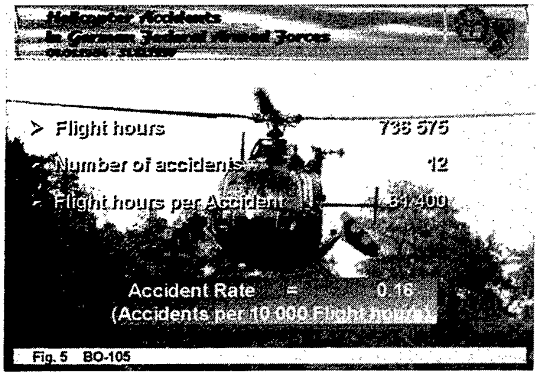


Fig. 5 BO-105

Another special feature of the BO is its restricted lateral stick control travel limit. In every helicopter, the neutral position of the stick is situated outside the cyclic center and respectively on the side, which corresponds to the rotor's sense of rotation. The higher the g-load during a turn flight the more the stick's neutral position moves to the direction of the turn. In other words, if you want to stop a steep right turn of a helicopter with a counter clockwise rotating rotor, you must first move the stick beyond its center position to the neutral position in order to prevent the helicopter from increasing its bank attitude and then significantly beyond the neutral position in order to return into a horizontal flight attitude. The peculiar feature of the BO is that when flying a quick tight turn at a low altitude the cyclic control travel limit to the left side may be too short to allow this turn to be stopped by simply moving the stick.

As mentioned before steep turns at high speeds can be stopped using the cyclic control stick. However, if the load factor is exceeded, both left and right turns may be accompanied by blade stalls. In practice, however, this does not involve any considerable effects. The rotor system is designed to withstand high load factors without allowing blade stall to occur. In some cases, though, the engine power may be not high enough to prevent the aircraft from loosing height, which is of course fatal during low-level flight. The fact that these aerodynamic peculiarities were not considered was the reason why during the period concerned three persons were killed, four persons seriously and two slightly injured. On the other hand, aircraft pilots have now a better understanding of these aircraft-related features.

Lowering the collective pitch of a helicopter will cause it to pitch nose-down. The faster the collective pitch is lowered the stronger the pitch motion will be. In case of the BO with its high steering response of $^2/_{10}$ sec and its ability to remain controllable even in the negative G range, the pilot may be confronted with a very unpleasant negative G motion combined with a rapidly increasing descent tendency if he lowers the pitch abruptly and strongly. In order to stop a flight attitude he must possibly react by pulling the pitch. In addition to the ever more dramatic flight attitude, however, the engine will not be able to provide the necessary power, which also leads to a reduction in steering response. Even if you have prepared the demonstration of such a maneuver, you need as an experienced aircraft pilot at least 1000 ft above ground in order to be able to stop this flight attitude without a flight accident.

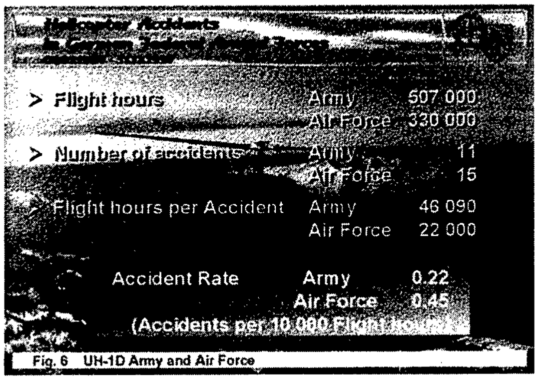
I have presented to you these phenomena in such detail, because we may possibly have lost aircraft due to these characteristics of the BO 105. However, we can not give evidence for this assumption since despite the many years' requirements of the Director of Bundeswehr Flight Safety our helicopters have not yet been equipped with crash recorders and not even voice recorders. In addition, there are no testimonies since no one has so far survived such a flight condition.

The BO helicopters were also subject to accidents caused by spatial disorientation. In one case, an aircraft flew into clouds at night. In this context, consideration should be granted to the fact that the BO 105 is an aircraft which is not designed for IFR flight and which is not even equipped with a radar altimeter. In addition, the Army Aviation Branch has a considerable number of aircraft pilots who are trained on non-IFR capable aircraft only. Under these circumstances, a transition into IFR flight is impossible. The trials of pilots who are not trained in IFR flight are therefore often inappropriate. From a flight physiological viewpoint I try to explain to the non-IFR rated pilot that VFR flying is first of all a matter of peripheral seeing whereas IFR flying requires central seeing which has to be learned in a special training.

Maybe another part of this problem is, however, associated with the emergency procedure, where pilots are taught to fly a return curve when flying inadvertently into clouds. To my mind and according to my knowledge of flight physiology a turning flight in this situation is the most reliable means to cause spatial disorientation if it did not exist before.

The good old UH-1D is operated by both the Army and the Air Force. This helicopter type was subject to 28 accidents, which were distributed to almost equal parts among both armed services, 13 accidents within the Army and 15 in the Air Force.

During the 28 accidents 32 persons were killed, 10 seriously and 19 slightly injured. 20 aircraft were destroyed. In eight cases in which the aircraft were only damaged only one slightly injured person had to be deplored.



Helicopter Accidents
[illegible]

> Flight hours Army 507 000
Air Force 330 000

> Number of accidents Army 11
Air Force 15

> Flight hours per Accident Army 46 090
Air Force 22 000

Accident Rate Army 0.22
Air Force 0.45
(Accidents per 10 000 Flight hours)

Fig. 6 UH-1D Army and Air Force

A look at the flight accident rates of the armed services reveals that, with reference to flight hours, the Air Force has to deplore most of the accidents. This is primarily due to the fact that no less than eight accidents went of the account of the SAR services alone. Therefore, the SAR service seems particularly prone to accidents. The Air Force is primarily responsible for the SAR service with military aircraft. Most of these missions are employed in the civil aeromedical rescue service. Only one army aircraft was involved in accidents which happened during the execution of civil air rescue missions. The remarkable thing about the Air Force's employment of the UH 1D in the very demanding air rescue mission profile is that it is only flown by one pilot. He is assisted by a flight engineer on the left seat who is in charge of radio communications and navigation. In this mission profile, the aircrew may always be obliged to transit to IFR flight or conventional night flight. In the Army, the UH-1D is always flown by two aircraft pilots and one flight engineer.

Another striking fact is that seven accidents occurred during night flying although the number of flight hours produced at night is significantly below that of flight hours registered during the day.

The training of emergency procedures such as emergency landings with power recovery or autorotation down to the ground took a high toll in aircraft (four aircraft destroyed - four aircraft damaged). Fortunately, these accidents caused only four slightly injured persons. Since the introduction of the UH 1D into the Bundeswehr this helicopter type had to undergo 21 real emergency landings. Eight of these landings ended up as flight accidents with one seriously injured person and four destroyed aircraft. In the same period 19 flight accidents happened during autorotation training, causing one seriously injured person and eight destroyed helicopters. In addition, 111 flight incidents were registered.

The two most serious accidents with in one case 13 and in the other case 9 killed aircrew members and passengers fall into the category of insufficient Crew Coordination.

A particularly serious accident happened during a mountain VFR flight when a drunken aircraft pilot with a blood-alcohol concentration of 250 mg/100 ml, or 2.5 $^0/_{00}$ ethanol, tried to descend below cloud cover while flying in high mountains under weather conditions which were significantly below the required minimum conditions. His drunkenness was credibly not recognized and caused the death of nine human beings. However, his alcoholism could have been identified quite well, and resulted in increased efforts to detect and nurse therapeutically alcoholic aircraft pilots and crew members. To my mind, the breakthrough in this field was achieved by promising the persons willing to undergo a therapy to get their pilot's certificate back after one year of abstinence after the therapy. Furthermore, this serious accident shows how important it is to have well trained and responsible flight surgeons on place in order to ensure intensive care and control of flying personnel.

Especially the large number of accidents where insufficient crew coordination and crew management was contributing factors must be an especially sobering truth. Lacking standardized voice procedures during the approach to a landing site, pressure of work, high psychological load, influence of non-flying personnel on the aircrew are only some of the key words adding up to this situation.

Often the flight briefings were insufficient so that the crew did not have a common planning basis. In other cases important information were not, not timely or wrongly reported so that the crew did not have a uniform knowledge of information. All in all, one can say that in many cases the crews put themselves under pressure without need and impose themselves unnecessary manifold tasks, which could have been prevented almost always if only they had predetermined their behavior in certain situations and distributed the roles before. Crew coordination and crew resource management is difficult to establish in a hierarchical organization, as is the Army. It is very hard to gain acceptance since training often aims at enabling the trainee to master problematic situations on his own. In addition, what is even more problematic is that this ability is even promoted by the Army. Accepting the fact that there are situations which go beyond the abilities of the individual, which are not necessarily due to performance deficiencies, seems to be hard for some self-confident member of the flying personnel. Nevertheless, the numbers speak clearly for themselves and efforts made to improve this situation must not be lessened.

Finally, these accidents revealed again the aerophysiological danger of spatial disorientation when flying a helicopter at night under VFR conditions. At the beginning of this year in February, the Army Aviation Branch lost one aircraft. It was flying at night under visual flight rules around the airbase when it was caught by a dense snow shower. The search for the aircraft was aggravated by the fact that the aircraft was painted white for a UN mission, which made it difficult for the light intensifier goggles equipped crew members of the search teams to locate it. The surviving flight engineer was maybe only found alive because he was a smoker and not injured to such an extent that he was not able to attract attention by using his cigarette lighter. This accident unveils again a deficiency which is already known for many years and which has been mentioned in many flight accident reports of the last years, namely the fact that the emergency radio sets are not man-packed. The emergency radios, which they carried along, were found in the wreckage of the aircraft and not accessible. To sum up, only a fortunate circumstance prevented the seriously injured survivor from freezing to death only four kilometers away from his home airbase.

Conclusions:

1. The intensive work invested in flight safety by the Bundeswehr is successful. The contents associated with **flight safety** are adopted and internalized by the personnel of the flying units. In this area, a basic attitude has been developed which one could wish to be also applied by the participants in the car traffic of our country.

2. Maintenance and repair of our aircraft are so good that only one accident went on their account, a positive fact that is often neglected.

3. In order to improve the already low number of flight accidents, more attention needs to be placed on the subject of **Crew Coordination** and **Crew Management.** To do so, the commanding authority must achieve the acceptance of this important subject in the middle-range posts of the flying personnel. Basic knowledge must already be taught in basic training.

4. The intensive and comprehensive aeromedical care of personnel participating in flight operations of field units contributes significantly to the prevention of flight accidents. A regular, careful and comprehensive examination at the Air Force Institute of Aviation Medicine, and the continuous aeromedical control and care of personnel at the home base and on mission, ensured by well trained and experienced **flight surgeons**, form the indispensable backbone of these positive results.

5. When the weapon systems EC 135 and TIGER are introduced, special emphasis must be placed upon the familiarization of aircraft pilots with the peculiarities associated with a **hingeless rotor system.**

Benefit of Crashworthy Design in Attack Helicopters: A Comparison of Accident Fatality Rates

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1. SUMMARY

Several NATO forces are currently procuring the latest version of the highly successful AH-64 Apache helicopter. As part of a program safety review, the literature was reviewed for evidence of an overall survival benefit of crashworthy helicopter design, as incorporated in the AH-64A. This benefit has been previously demonstrated in utility helicopters. Occupant survival in Class A-C AH-64A Apache accidents occurring from 1972-1996 was compared to survival during the same time period in AH-1 Cobra accidents. The analysis showed that the mortality rate was considerably higher for the AH-1, particularly in the 35-55 ft/sec vertical impact range. Head injuries were less frequent in survivable crashes involving the AH-64A than in survivable AH-1 crashes. These results, combined with the work of others, appear to confirm the benefit of crashworthy design in attack helicopter crash survival.

2. INTRODUCTION AND BACKGROUND

Over the next few years, several NATO countries will procure the latest version of the highly successful AH-64A Apache attack helicopter, manufactured by the Boeing Helicopter Company. This upgrade, known as the AH-64D (also Longbow Apache and, in the UK, the Westland AH-64), incorporates many significant improvements (Figure 1). Among these are the new fire control radar, improved weapons processors, a glass cockpit, improved data modem, and a multitude of engineering enhancements to overall system architecture and components [1].

In preparation for this significant mid-life aircraft upgrade, a review of the past performance of existing aircraft crash safety systems was undertaken. Using U.S. Army accident data, this paper will briefly review the performance of the various crashworthy features designed into the original AH-64A, and will gauge the effectiveness of its unique flight helmet (the Integrated Helmet and Display Sighting System [IHADSS]) in preventing head injury (Figure 2). The detailed characteristics of the IHADSS helmet have been reviewed elsewhere [2]. These considerations could be important in prioritizing potential system improvements (e.g., removing specific injury hazards, replacing the existing helmet, etc.).

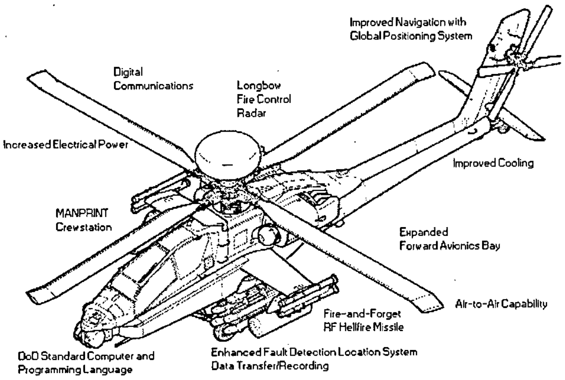

Figure 1. Features of the Boeing AH-64D [1].

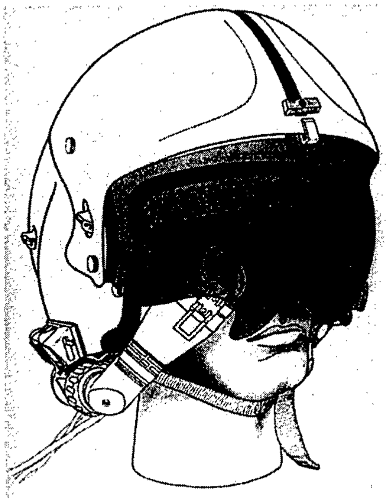

Figure 2. The Integrated Helmet and Display Sighting System (IHADSS).

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

2.1 Crashworthy Helicopter Design

Given identical impacts, the occupants of an aircraft designed to "crash safely" will often suffer less severe injury. A brief review of essential elements of helicopter crashworthy design will provide a background for understanding the Apache's safety features. The effect of the AH-64's crashworthy design on actual crash survival will then be considered.

Although the basic principles of crashworthy aircraft design have been known for years, only crop dusting aircraft were manufactured with any serious attempt at crash injury prevention [3]. Then, during the Vietnam conflict, the high rate of helicopter crash injuries and deaths prompted the U.S. Army to fund the research and development necessary to facilitate crashworthy aircraft design. This work culminated in the UH-60 Black Hawk (Figure 3) and AH-64 Apache helicopters (Figure 4), which were designed ab initio to incorporate sound crashworthy principles.

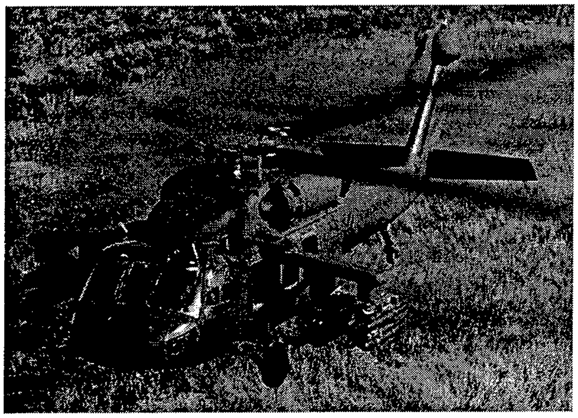

Figure 3. The UH-60 Black Hawk helicopter (Official U.S. Army photo).

2.2 Crashworthiness and the AH-64A

Shanahan defined crashworthiness as "the ability of an aircraft and its internal systems and components to protect occupants from injury in the event of a crash." [3]. The basic components of crashworthy design are summarized in the acronym, "CREEP." These features will be discussed briefly in the context of the AH-64 helicopter (Figure 4).

(C)ontainer refers to the importance of preserving the integrity of the occupiable spaces within the crashing aircraft. Examples from the AH-64 aircraft include the roll-bar built into the blast shield separating the pilot and copilot/gunner (CPG), and the collapsible gun turret mount (to avoid intrusion into the cockpit during impact). It should be mentioned, however, that a design problem has been noted in a small number of AH-64A accidents. In order to accommodate the nose gun turret, the aircraft main keel beam ceases at the bulkhead between the pilot and CPG stations. Engineers at the US Army Aeromedical Research Laboratory (USAARL) believe that, in certain AH-64A mishaps, this has allowed a loss of structural integrity around the forward cockpit (personal communication, J. McEntire, 1997). One effect of this weakness is that as the CPG cockpit is distorted during the accident sequence, the seat stroke path may be blocked, generating undesirable forces that have caused back injuries.

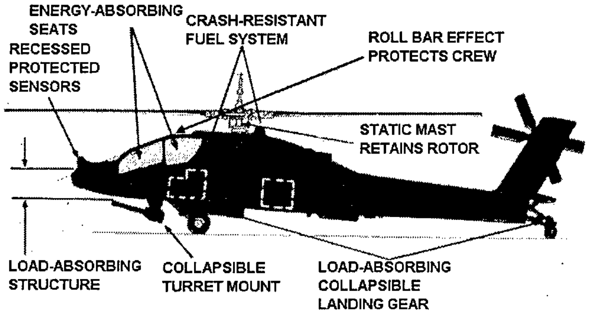

Figure 4. Crashworthiness design features of the AH-64A Apache helicopter.

(R)estraint is of obvious importance and appropriate devices are incorporated in all aircraft. The AH-64 does have particular need for good restraint, especially in the front cockpit, because of the head strike hazard presented by the optical relay tube (ORT). To this end, prototype airbags and inflatable restraint systems have been developed for the AH-64 (although these may be superseded by a redesign eliminating the ORT).

(E)nergy absorption, particularly in the vertical direction, is critically important in helicopter crash injury prevention [4]. The AH-64 relies heavily on load-attenuating fixed landing gear, combined with energy-absorbing seats. Together, this system has proven extremely effective. Shanahan points out that fatalities are rare in vertical impacts up to approximately 50 ft/sec (15.2 m/sec) in the AH-64A [3]. The areas under the floor and behind the aircraft nose are also designed to absorb impact energy.

Local (E)nvironment, or the aircraft interior, should be "delethalized" to provide the least opportunity for contact-type injuries. The AH-64 has the usual helicopter strike hazards of the cyclic and collective sticks, and as mentioned above, does have the additional hazard of the ORT close to the CPG's face. One feature of the AH-64A that has contributed to head injury is the overhead circuit breaker panel to the left of the pilot's head. The AH-64D redesign has moved this object and eliminated the hazard.

(P)ostcrash factors such as fire, fumes, fuel, oil, and water can influence survival. An important factor in helicopter crash survival is fire. Prior to the U.S. Army's incorporation of crashworthy fuel systems in the 1970s, up to 42% of deaths in survivable crashes were due to fire [3]. Since then, only a handful of fire-related deaths have occurred, most in aircraft flying with special non-crashworthy fuel cells (i.e., long-range wing tanks). Crashworthy fuel systems have essentially eliminated serious fire in U.S. Army helicopter crashes, reducing the consequences of post-crash unconsciousness and entrapment and all but eliminating burns as a crash-related injury.

In summary, the AH-64 is an aircraft that was designed to crash safely. Notwithstanding specific residual hazards (e.g., keel beam and ORT problems), the occupant is much safer in this aircraft (or the UH-60 Black Hawk) than in other helicopters. As Shanahan put it, the "Apache (has) demonstrated the ability to absorb hard landing impacts of up to 20 ft/sec (6.1 m/sec) with minimal or no damage to the aircraft and no injury to the occupants. For most other helicopters, similar impacts would have resulted in a destroyed airframe and the potential for serious injury to the occupants." [3].

Figure 5. The UH-1 Iroquois helicopter (official U.S. Army photo).

2.3 Effectiveness of Crashworthy Design Techniques

In 1992, Shanahan showed that survival in UH-60 Black Hawk helicopter crashes was dramatically improved over survival in crashes of an older utility helicopter, the UH-1 Iroquois (Figure 5) [5]. Figure 6 depicts the probability of sustaining a fatal injury as vertical velocity at impact increases. Most UH-60 occupants survived vertical impacts in the 40-60 ft/sec range, while virtually all UH-1 occupants were killed in impacts of this severity. Comparing the UH-60 to the UH-1 was considered reasonable, as both helicopters are utility-class with quite similar missions. This difference in survival was attributed to the crashworthy features of the UH-60.

3. METHODS

3.1 Attack Helicopter Crash Survival Rates

Using Shanahan's technique and data obtained from the U.S. Army Safety Center (USASC) accident database, occupant survival in Class A-C AH-64A Apache accidents was compared to survival in Class A-C AH-1 Cobra accidents occurring from 1972-1996 (Table). The Vietnam-era AH-1 (Figure 7), having very few crashworthy design features, was considered to be the most appropriate comparison helicopter for the AH-64, as both are attack helicopters with a tandem seating configuration.

3.2 Apache Helmet Performance

To date, the only helmet operationally used by U.S. Army AH-64A aircrew has been the IHADSS helmet. To assess performance of this helmet, information regarding head injuries suffered by AH-64A crewmembers involved in Class A crashes between 1983-1996 (inclusive) was extracted from the USASC database and summarized. Head injury was defined as any recorded injury to an area of the head normally covered by a protective flight helmet (i.e., excluding the face). Analysis was restricted to occupants of survivable or partially survivable mishaps (hereafter collectively referred to as "survivable"). The rate of head injury in AH-64A mishap pilots was then compared to the rate in AH-1 mishap pilots during the same time period.

Table. U.S. Army aircraft accident and incident classifications [6]. Meeting either the criterion cost or the injury severity qualifies an accident for a given class. An accident is also considered Class A if there is total loss of an aircraft, regardless of cost.

Accident Class	Property Cost	Injury Severity
A	>$1,000,000	fatality or permanent total disability
B	>$200,000	permanent partial disability or >4 days hospitalised
C	>$10,000	lost-worktime case
D	>$2,000	any other injury requiring treatment
E	<$2,000	none

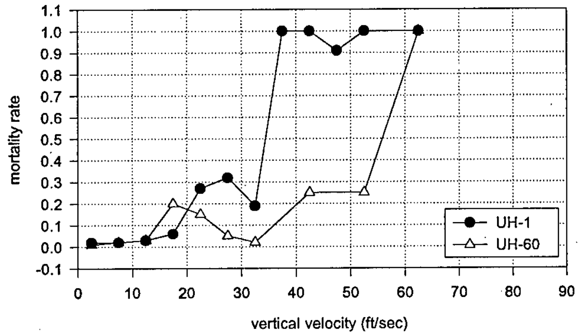

Figure 6. Shanahan's comparison of fatality rate between a "crashworthy" helicopter (the UH-60) and an older helicopter lacking most crashworthy design features (the UH-1) [4]. Note that in 40-60 ft/sec (12.2-18.3 m/sec) impacts, most UH-60 occupants survive, but virtually all UH-1 occupants are killed. The study included accidents 1979-1990.

Figure 7. The AH-1 Cobra helicopter.

4. RESULTS AND DISCUSSION

4.1 Attack Helicopter Crash Survival Rates

Figure 8 shows that the mortality rate is higher for the AH-1, compared to the AH-64A, particularly in the 35-55 ft/sec (10.7-16.8 m/sec) vertical impact range. Thus, the benefit of crashworthy design principles documented by Shanahan for utility helicopters [5] appears to hold true in attack helicopter design as well. These results also confirm the recent work of Shannon and Shanahan [7].

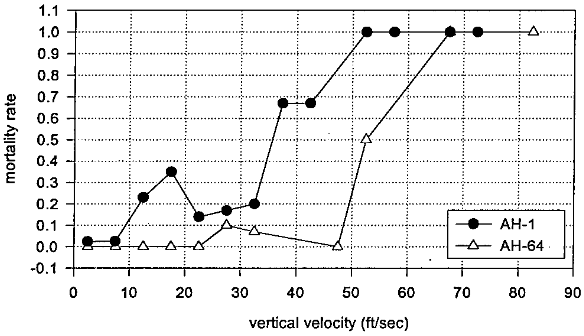

Figure 8. Comparison of accident fatality rates between AH-64A Apache and the Vietnam-era AH-1 Cobra helicopters 1972-1990. Note that in 35-55 ft/sec (10.7-16.8 m/sec) impacts, AH-64A occupants have a considerably better chance of surviving than do AH-1 occupants.

4.2 IHADSS Helmet Performance

In the 34 survivable AH-64A Class A mishaps occurring between 1983-1996 (inclusive), there were 14 head injuries in 13 occupants of 10 aircraft. None of these occupants died,[1] but one injury was critical and 7 were major (according to U.S. Army criteria). The most common injury was concussion (n=10). The investigating flight surgeon felt that the IHADSS helmet had reduced head injury severity in 9 individuals, and that the helmet had functioned as designed for 11 of the 13 victims. The two cases in which the helmet failed to perform as designed both involved helmet retention failure, one due to a loose nape strap and the other to failure of a snap fastener.

The risk of suffering head injury in a survivable Class A mishap (1983-1996) for an AH-64A crewmember was 19.7% (13/66 occupants). An AH-1 crewmember involved in a survivable Class A accident during the same period had a slightly lower chance of sustaining a head injury (8/56 or 14.2%). However, three of the eight AH-1 crewmembers sustaining a head injury died as a result of that injury, while none of the head injuries to AH-64 occupants was fatal. (AH-1 pilots wear a slightly modified SPH-4 flight helmet.) It should also be noted that a greater proportion of Class A AH-1 accidents are nonsurvivable than are Class A AH-64A accidents (12/42 vs 4/41, Fisher's Exact Test, p=0.05).

Although the IHADSS helmet is generally considered safe and effective, shortcomings have been noted. In one AH-64 accident, a serious head injury resulted from a direct blow to the IHADSS visor cover. USAARL researchers found that a blow to this area "could transmit the impact energy directly to a portion of the helmet where there is no energy-absorbing liner." [8]. The IHADSS helmet was also criticized for its large volume, which presents a large potential for direct contact with cockpit surfaces during an impact sequence.

USAARL researchers have used data and life support equipment from hundreds of serious helicopter accidents to make significant improvements in crashworthiness and helmet safety. Injury trends, when confirmed with laboratory research, have resulted in changes to the aircrew helmet standards. This approach has resulted in a helmet design that minimizes the types of injuries seen in military helicopter crashes.

DISCLAIMER

The views, opinions and/or findings contained in this report are those of the author and should not be construed as an official United States Army position, policy, or decision, unless so designated by other official documentation. Accident data from the U.S. Army Safety Center cannot be used as evidence or to obtain evidence in determining the misconduct or line-of-duty status of any personnel; to determine liability in claims against the government; or as evidence to determine pecuniary liability. They are not to be used or introduced as evidence in courts of law. They may be used for safety purposes only and may not be used for any adverse administrative or disciplinary purposes (U.S. Army Regulation 385-40).

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[1] Not included in this analysis were two fatalities due to head injury whose crew position was judged non-survivable by the board flight surgeon. One of these suffered a blade strike to the head and the other sustained multiple severe head and abdominal injuries. These two accidents were coded by USASC as "partially survivable."

ACKNOWLEDGEMENT

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AEROMEDICAL AND DESIGN ISSUES OF THE HELICOPTER AIRBAG RESTRAINT SYSTEM

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SUMMARY

Bodily contact with cockpit structure remains the leading cause of serious and fatal injury in survivable helicopter mishaps. As a countermeasure, the U.S. Army is developing a cockpit airbag system (CABS) for use in the UH-60 Black Hawk as a supplemental restraint system. This program was initially considered a technology transfer effort, transferring automotive airbag technology into the military helicopter cockpit. Unique helicopter crash kinematics caused the performance requirements to diverge from automotive requirements. As a result, many of the technical aspects of the airbag restraint system were readdressed, from airbag fabric selection to sensing the crash. Many design challenges remain, such as accommodating the smallest to largest occupants and determining the "FIRE" thresholds. Finally, the method of assessing system effectiveness must be addressed. Various performance requirements, rationale, lessons learned, and operational issues of the cockpit airbag system are discussed.

SUBJECT MATTER KEYWORDS

Airbags
Aircrew injury
Cockpit airbags
Cockpit airbag system
Crash protection
Crash sensor
Inflatable restraints
Joint cockpit airbag system
Gas generator
Occupant restraint
Restraint systems

1. INTRODUCTION

Head and upper torso injury remains the leading cause of serious and fatal injury in the U.S. Army rotary-wing crash environment [1]. Prior efforts to reduce the severity of head injury has focused on improved helmet design. Development of improved passive restraint systems has slowed with the adoption of the 5-point restraint system in the Army's UH-60 Black Hawk and AH-64 Apache helicopters (Figure 1 [2]). However, injury statistics suggest that additional aircrew protection is required to reduce the incidence of head and upper torso trauma.

The success of automotive airbag systems prompted military injury researchers and materiel developers to consider incorporating similar technology into the helicopter cockpit. The initial approach was to utilize the available automotive technology in this integration effort. During the development process, shortcomings were identified in automotive technology which limited its utilization. Each potential application and cockpit configuration presents its own design challenges. Further, true performance evaluation for cockpit airbag systems remains elusive due to lack of representative fuselage structures in which to conduct crash tests. However, the injury criteria established by the National Highway Traffic Safety Administration for evaluating effectiveness of automotive airbag systems have been adopted for assessing CABS performance in dynamic tests.

2. BACKGROUND

Airbag research and developmental efforts have been conducted by several organizations within the U.S. Army. A summary of the significant events of these efforts is provided in Table 1. Two separate in-house research and development (IRAD) efforts were initiated by two separate Army activities in the late 1980's. The first was by the Army Aviation Applied Technology Directorate (AATD) in early 1988, which sought to establish the state of automotive airbag technology. AATD developed and derived the initial concept for a three-bag-per-cockpit approach (Figure 2), to protect the attack helicopter aviator [3]. The second activity was initiated by the U.S. Army Aeromedical Research Laboratory (USAARL) in late 1988 to explore the concept of using rapidly inflating air cushions and to assess the technology involved in reducing the severity of head strikes on the gun sight system during actual crashes [4].

Table 1. History of CABS significant dates.[1]

DATE	EVENT
Early 1988	AATD IRAD
Late 1988	USAARL IRAD
August 1989	SBIR Phase I
Dec 1991	SBIR Phase II
August 1993	Joint Aero. Commanders Group (JACG) Brief
Sept 1993	USAARL Study
May 1994	SBIR Phase III, JCABS
June 1995	AH-64 CABS
April 1996	UH-60 CABS
July 1996	AH-64 CABS canceled
Dec 1997	UH-60 CABS delay
June 1998	UH-60 CABS Critical Design Review (CDR)
June 1998	OH-58 CABS
Fall 1999	UH-60 CABS fielding (est)

[1] see text for discussion and abbreviations

Paper presented at the RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", held in San Diego, USA, 19-21 October 1998, and published in RTO MP-19.

The results of the AATD effort resulted in a Phase I Small Business Innovative Research (SBIR) award in August 1989 to Simula, Inc., to conduct a paper analysis and to develop a conceptual design. Their results were encouraging, and in December 1991, a follow-on Phase II effort was awarded to produce working models. This effort culminated in a working system demonstrated in two AH-1 fuselage crash tests [5].

USAARL conducted a study in 1993 which predicted CABS effectiveness in the U.S. Army helicopter fleet. This study concluded that airbag installation could result in a 23 percent reduction in aviator fatalities and a 50 percent reduction of aircrew injury [6].

Results of the AH-1 crash tests and the USAARL study were briefed to the Joint Aeronautical Commanders Group (JACG) in August 1993. The JACG directed that the Army assume lead responsibility for the development of the Joint Cockpit Airbag System (JCABS), with cooperation and assistance from the U.S. Air Force, U.S. Navy, U.S. Coast Guard, and the Federal Aviation Administration (FAA). This directive resulted in a jointly-sponsored contract to Simula Government Products in May 1994 to complete the JCABS advanced development and produce a JCABS demonstration based on the UH-60 helicopter.

Prior to completion of the JACG-directed development effort, funding was provided by the Program Manager of Aircrew Integrated Systems (PM-ACIS) of the Army Aviation and Troop Command (ATCOM) to AATD to award contracts for specific airframe CABS development. The AH-64 CABS development contract was awarded in June 1995, and the UH-60 CABS development contract was awarded in April 1996. However, prior to a Critical Design Review (CDR) for the AH-64, the contract was canceled due to the AH-64 upgrade (Longbow) program, which involved a new cockpit design for the forward crewstation, which adversely impacted the AH-64 CABS design and development effort.

The aggressive schedule of the UH-60 CABS development effort created a high risk program with little margin for technical delays. Technical problems were realized in December 1996, and the program was rescheduled with an 18 month slip. The UH-60 CABS is now scheduled for fielding in the fall of 1999.

Recently, funding was provided by PM-ACIS to AATD to initiate development of a CABS system for the OH-58 Kiowa Warrior. In June 1998, a contract was awarded to Simula Safety Systems, Inc., to initiate development efforts on the OH-58 CABS.

3. COCKPIT AIRBAG SYSTEM

For existing Army aircraft platforms, the CABS is a retrofit system with two kits, the A-kit and the B-kit. The A-kit consists of the aircraft integration components, such as the wiring harnesses, a modified glare shield, attachment hardware, and aircraft modifications. The B-kit is comprised of the crash sensor and airbag modules. New aircraft, such as the RAH-66 Comanche, will have the CABS system designed into the cockpit, if funded.

3.1 Cockpit integration

Cockpit integration remains a formidable task. For the attack type aircraft, the three-bags-per-cockpit configuration is considered optimal. In aircraft with a side-by-side cockpit seating arrangement, a four bag concept is considered optimal. In this configuration, illustrated in Figure 3, a middle bag is considered unnecessary unless contact is expected between the two occupants. The lateral (outboard) bags would typically be attached to side armor panels or support structure. Locating acceptable mounting locations for the forward bag is difficult in modern densely clustered instrument panels and small cockpits. Often, the only available mounting location is on the instrument panel glare shield.

3.2 Bag Design

Bag shape, volume, and deployment patterns affect a variety of factors, including visibility, flight control interference, optimal crew protection, and reducing the risk of creating novel injury mechanisms. Utilization of automotive airbag materials was not possible since automotive materials did not meet FAA fabric burn requirements. The new material selection and development effort required trade-offs between porosity, weight, folding compactness, ease of fabrication and assembly, strength, flame resistance, availability, and cost. Additional consideration was given to fabric abrasiveness and tear/puncture resistance. Automotive airbags are vented to allow excessive bag pressure to escape, especially when the occupant flails into the bag. The cockpit airbag, on the other hand, is completely sealed to provide prolonged inflation time for helicopter crashes involving multiple impacts.

3.3 Gas Generator

The gas generator is a critical component in the successful airbag design. Automotive gas generators burn rapidly to quickly inflate the bag for the typical single impact car crash. The cockpit airbag gas generator must rapidly inflate, but should also burn cleanly at a low temperature to minimize the cooling. (CABS bag deflation is dependent on thermodynamic cooling.)

Residual gas generator by-products also must be minimized, for they can result in the bag tearing and/or burning, which would allow the gas to escape, thereby reducing the protection from secondary aircraft impacts.

Finding a manufacturer willing to develop new gas generator formulations was difficult due to the Army's relatively small requirement (less than 10,000 units, equal to approximately one day's output from an automotive assembly line). A suitable and willing vendor was eventually found and production is now underway.

3.4 Crash Sensor

Automotive crash sensor technology is proprietary and highly protected by the manufacturer. Because automotive crash sensors will not sense the omnidirectional crash pulses experienced in helicopter crashes, a new crash sensor was developed by a Simula and Government development team. Since little crash acceleration data are available on helicopter crashes, it was desirable to develop a reprogrammable sensor which would record the crash dynamics, and differentiate between normal and crash environments. Two crash sensors are now available to the Government which provide these characteristics.

3.5 Fire Criteria

The algorithm and criteria utilized by the crash sensors have been a highly debated topic among the Government and Simula engineers. The crash sensor, algorithm, and fire criteria are critically important to the CABS system. If the system fires too late, the CABS effectiveness is minimized. If it fires too soon, it could actually induce a crash or prevent the aviator from applying positive control inputs during the crash sequence. Review of the U.S. Army Safety Center database for vehicle crash accelerations provide the estimated peak G values, but do not provide a determination of "when" a fire command should be issued during the crash sequence. It is expected that once CABS systems have been fielded and actual system performance data recovered, the firing thresholds and algorithm may be refined to optimize system performance.

4. OPERATIONAL ISSUES

Numerous operational concerns have been identified by potential users (aviators) and materiel developers, regarding the use of airbag restraint systems in operational aircraft. Some of the more critical issues are presented and discussed below.

4.1 Emergency Egress - Land

Operator egress after airbag activation is a concern for aviators. The concern is that the deflating bag material may impede and prevent timely egress from an aircraft where post crash hazards, such as fire, are possible. During the UH-60 JCABS design effort, tests were conducted to address any interference with egress related to the post-deployed airbag system. At the U.S. Army Aviation Technical Test Center (ATTC), land emergency egress tests have been conducted in various flight gear configurations including summer, winter, protective armor, and chemical defense aviator ensembles. Aviators representing a stature range between the 5th percentile female up to the 95th percentile male were used. No significant interference with emergency egress was found.

4.2 Emergency Egress - Water

Another scenario is a crash into water, after which the remaining bag gas partially inflates the bags, thereby impeding an underwater escape.

Underwater escape evaluations have been conducted under the guidance of the Naval Aviation Medical Institute and the Naval Aviation Water Training Program Model Manager in modified U.S. Navy dunker facilities [7]. The dunker was modified to represent the SH-60 door and emergency escape hatch openings and included the airbag forward and lateral modules. Phase I of the evaluations assessed occupant safety, clearance, and ability to reach exit release handles after the dunker was lowered into water, both upright and inverted. Phases II and III included actual underwater egress efforts, with Navy divers and qualified survival instructors. The Phase II effort was made to assess safety and to develop egress procedures. The Phase III effort culminated with actual helicopter aviator volunteers performing underwater egress using the procedures developed during Phase II. Throughout the tests, the airbags were inflated to various levels to represent different airbag volumes and potential blockage scenarios, and the seats were adjusted in height to account for different levels of seat stroke.

Debriefing of the subjects revealed that some experienced snagging or blocking of their feet and legs by the frontal bags, and pushing on the shoulders and heads by the side mounted bags. Some subjects reported the airbag(s) obstructed their access to the simulated emergency exit handles during roll and when inverted. All subjects commented the airbags did not significantly deter their emergency egress during the tests. They also all commented that, "If the airbags are in the aircraft, then they should be included in the 9D5A [dunker] training." Numerous limitations were identified, including the limited test subject population, the controlled and ideal conditions of the 9D5A dunker, differences between actual SH-60 cockpit clearances and dimensions, lack of actual escape hatches, minimal snag hazards, and the lack of environmental stresses (sea state, water temperature, water depth and lighting). Given these test limitations, the Navy concluded that, "there is still some level of risk to aircrew underwater egress upon the incorporation of airbags in the cockpit." [7]

4.3 Inadvertent Deployment

One obvious concern frequently expressed by Army aviators is, "what happens when the airbag system inadvertently activates in flight?" The concern relates to the fact that the deployment event or post-deployed bags could cause a temporary loss of aircraft control, impede aircrew efforts to control the aircraft, or induce a debilitating injury.

In an effort to address this concern, 12 inadvertent deployment tests were conducted in the pilot station of an AH-64 trainer simulator during the SBIR Phase II effort. In all 12 deployments, no loss of control or injuries were experienced [5]. Test subjects described the in-flight deployment as a "non-event." These results suggest that airbag inflation should not be a problem for aviators to maintain aircraft control.

Direct application of the AH-64 test results to other aircraft (e.g., the UH-60) is not possible because of recent significant changes in the bag geometry and the gas generators. To address this issue, the ATTC conducted a CABS deployment in a parked UH-60 in late June 1998. This test was conducted to determine if the deploying bags would interfere with the cyclic and collective flight controls. Study of the high speed films revealed the frontal bag made slight cyclic contact during its inflation rebound. Aviators witnessing the test and reviewing the films indicated the flight control contact was insignificant and would be compensated by the aircraft's trim control system.

Additional inadvertent deployment tests are planned in the USAARL JUH-60 research flight simulator. Plans are being made to assess the pilot's "startle" effect, the effect on night vision goggle use, injury risk, cockpit noise during deployment, as well as post-deployment bag stowage techniques for mission continuation. These tests are planned for January 1999.

Efforts to reduce the likelihood of an inadvertent deployment are continuing. These efforts are based on increasing system reliability and minimizing the risk of system failure, and include high reliability components and a fail-safe system. Determination of activation criteria is critical to this effort to reduce the system sensitivity to aircraft vibration and flight maneuvers during normal and emergency operations. Numerous flight tests have been conducted to collect flight vibration signatures at the desired crash sensor mounting location under various operational and flight environments. These data were used to exercise the deployment algorithm to assess its susceptibility to producing a false "fire" decision. Unfortunately, data are not available for the instances of in-flight emergencies such as tree strikes or aircraft sub-component failures which result in high aircraft vibrations, but not crashes.

4.4 NVG Compatibility

Night vision goggles (NVGs) amplify available light to the user. Early tests during the Phase II SBIR effort indicate that illumination resulting from gas generation and bag deployment caused the typical AN/PVS-6 (ANVIS) to shutdown for a ½-to-1-second period. This undesirable effect was mitigated by using a darker bag material as opposed to the original light colored bag. The new gas generator and bag material combination developed for the UH-60 CABS is yet to be tested for NVG compatibility. A partial evaluation will be conducted concurrently with the inadvertent deployment tests scheduled in the USAARL JUH-60 flight simulator.

5. SYSTEM EVALUATION

Evaluation and assessment of CABS performance is difficult. The CABS must demonstrate the potential to reduce injury during dynamic crash events, but must also be shown to not introduce injury during an inadvertent deployment.

5.1 Static Test Conditions

During the UH-60 CABS development, Simula Government Products, Inc., has conducted bag deployment tests with the small 5th percentile female and large 95th percentile male Hybrid III test manikins [8]. These tests were conducted in a UH-60 cockpit mockup with the manikins pre-positioned in vulnerable positions, leaning forward and/or laterally into the path of the deploying bag. These tests were conducted with the cockpit mockup stationary, under a static 1g environment. The instrumentation readings from the manikins indicate the loads and accelerations experienced do not approach the injurious values typically associated with dynamic tests. Thus, serious injury is not expected as a result of an inadvertent deployment. However, these test manikins do not provide data to indicate if facial or local tissue injury would result, and no instrumentation was available in the upper extremities to suggest the risk of an upper limb injury.

5.2 Dynamic Test Conditions

Numerous UH-60 developmental dynamic tests have been conducted by Simula Safety Systems, Inc. The parameters used in these tests are illustrated in Figure 4. Recently, tests without the CABS were conducted to provide baseline data to be used for accurate assessment of the CABS injury reduction potential. It was assumed that the CABS would clearly reduce the injury potential if, during baseline tests, the manikin had struck a cockpit structure. Such an injury reduction benefit was not evident if the manikin did not strike a cockpit structure or if the strike was only a glancing blow during the baseline tests. This is partly a limitation of the rigid test fixture which does not adequately characterize the structural deformation typically experienced by the fuselage during helicopter crashes. One attempt to correct this shortcoming is to remove the seat reinforcements that were introduced to preserve the seat for subsequent tests. Another attempt utilizes a full cockpit mockup as opposed to a half cockpit mockup structure. These improvements will be incorporated in a qualification test series scheduled for the Fall of 1998.

5.3 Injury Criteria

Injury data from the dynamic tests will be interpreted by an Injury Assessment Team (IAT) consisting of biodynamic experts from Simula, U.S. Army, U.S. Navy, U.S. Air Force, and the FAA. This team debated and selected the primary injury assessment criteria provided in Table 2, adopted from the National Highway Transportation Safety Administration.

Table 2. Injury assessment criteria.

Measurement	5th % Female	50th % Male	95th % Male
HIC (36 ms)	1,113	1000	957
Chest Acc. (3ms, g)	73	60	54
Neck Tension (lb)	495	742	911
Neck Comp. (lb)	600	900	1104
Neck Shear (lb) (Fore/aft)	465	697	856

Upon conclusion of various dynamic test series, test results are provided to the IAT members for review. When test results are not obvious or are controversial, the IAT will convene to jointly review the high speed films and to openly debate and interpret the test results.

6. CONCLUSIONS

There is real potential for cockpit airbag systems to reduce injury severity and improve survivability in helicopter crashes. One of the original cost-cutting premises of the CABS program, the transition of automotive airbag technology into the cockpit, was not realized. That and many unexpected technological challenges presented themselves to the contractor and Government development team. Early identification of the technical issues, operational concerns, and performance requirements is critical to development of a successful system. Good teamwork through all phases of the CABS development effort has successfully met most of these challenges. Plans are in place to achieve the remaining few. A critical milestone will be the inadvertent deployment test planned in the JUH-60 flight simulator. Successful results of that test will likely result in fielding of a cockpit airbag system into the Army's UH-60 helicopter fleet. However, final determination of the CABS potential benefit won't be realized until actual crashes occur with lives saved.

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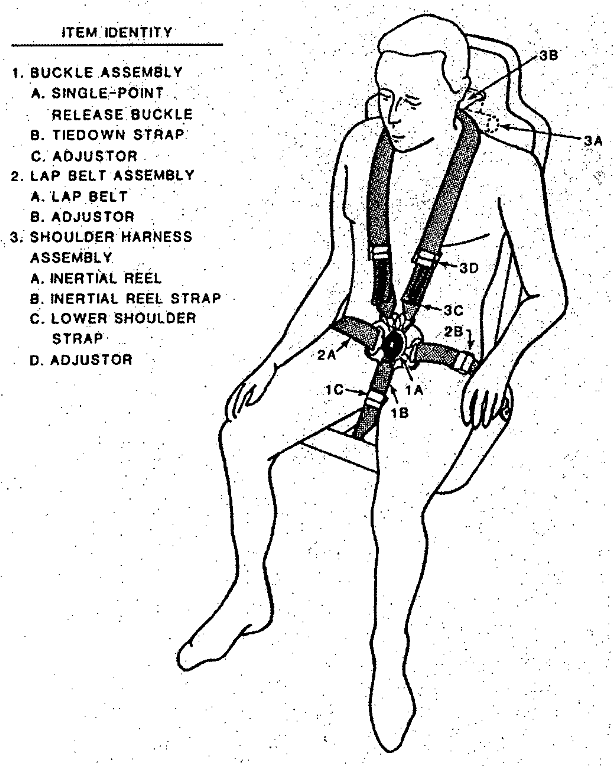

Figure 1. Conventional 5-point restraint harness.

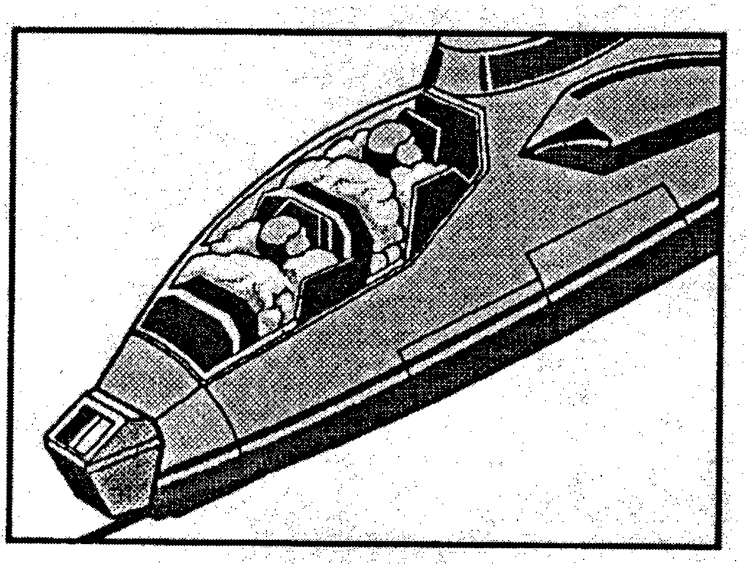

Figure 2. Conceptual attack helicopter cockpit airbag positions.

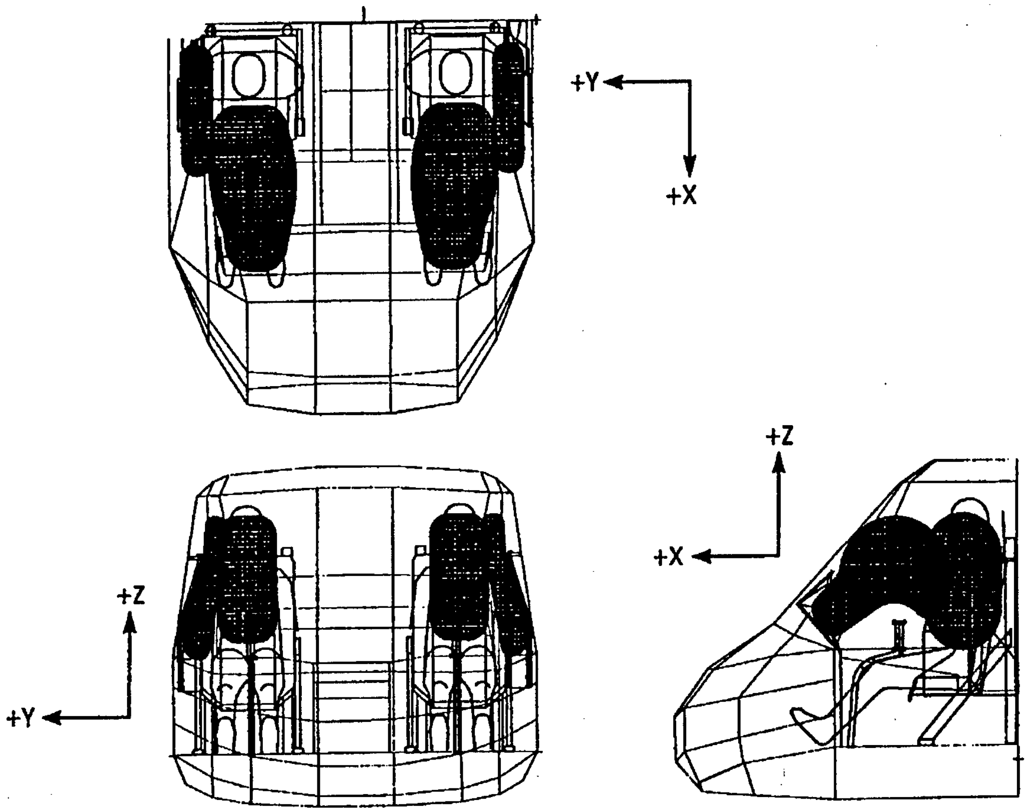

Figure 3. UH-60 CABS conceptual drawing.

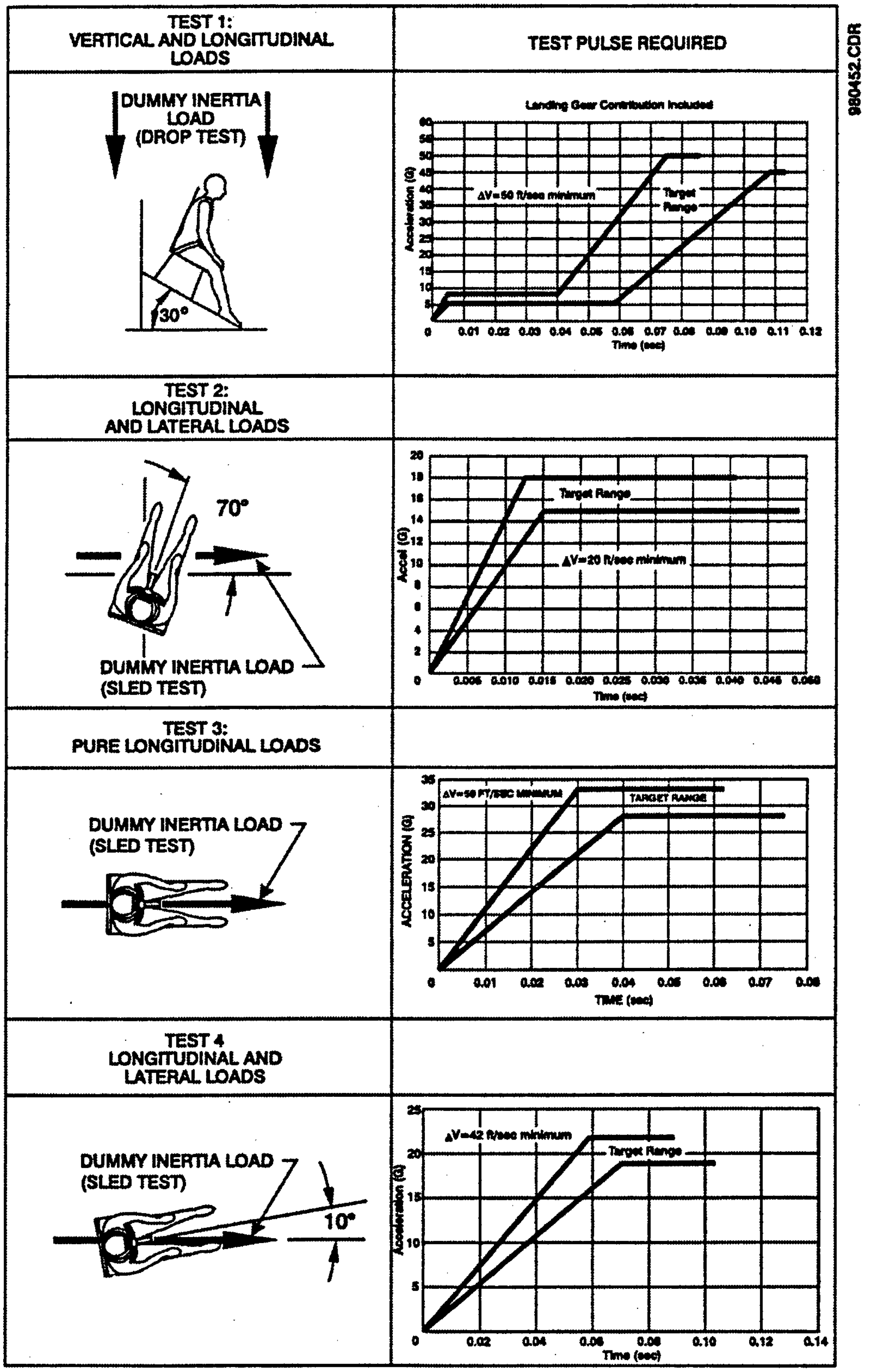

Figure 4. UH-60 CABS dynamic test conditions.

Mass and Location Criteria of Head-Supported Devices Using Articulated Total Body Simulations

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1. SUMMARY

Limits on the mass of head-supported devices (HSDs) and center of mass location were investigated using the biodynamic response of occupant models during simulated helicopter crashes. The articulated total body (ATB) model was used to simulate five different crash pulses, three seat stroking distances, and three HSD masses with the mid-sized Hybrid III manikin as the occupant model. The centers of mass were placed at 49 positions in each of three planes: (1) the mid-sagittal plane of the head, (2) a plane located 3 centimeters to the right of the mid-sagittal plane, and (3) a plane 3 centimeters to the left of the mid-sagittal plane. Moments and forces produced by the ATB simulations at the head-neck interface (occipital condyles) were compared to established injury thresholds to determine the risk of neck injury. Acceptable combinations of head-supported masses and locations then were established for the given impact conditions. Acceptable HSD mass and location were highly dependent on impact condition and the seat stroke.

2. LIST OF SYMBOLS AND ABBREVIATIONS

ATB	Articulated total body
cm	Centimeters
CM	Center of mass
CPG	Co-pilot/gunner
FLIR	Forward looking infrared
HDU	Helmet display unit
HNI	Head/neck interface
HSD	Head-supported device
IARV	Injury assessment reference value
IHADSS	Integrated helmet and display sighting system
kg	Kilogram
lb	Pound
msec	Milliseconds
$m \cdot sec^{-1}$	Meters per second
N	Newton
NRP	Normalized response parameter
NVG	Night vision goggles
ΔV	Velocity change

3. SUBJECT MATTER KEYWORDS

Articulated total body
Biodynamic simulations
Center of mass
Head-supported devices
Head-supported mass
Helmet
Mass

4. INTRODUCTION

During the evolution of Army rotary-wing aviation, the amount of head-borne mass has steadily increased. This is due in large part to the evolution of aircrew helmets. Prior to the 1950's, aircrew flight helmets were nothing more than leather or cloth caps. Beginning in the 1950's, hard shell helmets were introduced into service. These helmets provided a dramatic improvement in head impact protection and provided greater sound attenuation and integral communications equipment. These benefits came at the price of increased helmet mass – the mass of these hard shell helmets was three times that of their leather and cloth counterparts [1]. Furthermore, with the advent of night vision systems during the 1980's, helmets began to serve as mounting platforms for numerous combat-essential devices. Among these devices are night vision goggles (NVGs) and the AH-64's integrated helmet and display sighting system (IHADSS) helmet display unit (HDU) which displays weapon targeting information, forward looking infrared (FLIR), and flight instrumentation symbology [1]. With the addition of each of these systems, the amount of head-supported mass has steadily grown.

The addition of HSDs has increased the risk of neck injury due to inertial loads generated during helicopter crashes. Furthermore, the emergence of new helmet design concepts has raised new design and safety questions. For these reasons, this study was undertaken to evaluate the relationship between HSD mass and center of mass (CM) placement for a number of different impact conditions and seat stroking distances.

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5. BIODYNAMIC SIMULATIONS

A widely used tool for biodynamic simulation and accident reconstruction is the ATB simulation software [2, 3]. Given a number of body segments connected by mathematical models at common joints, ATB automatically formulates the differential equations that govern the motion of the body segments.

The model is driven by acceleration pulses that approximate crash profiles. ATB then integrates those equations to compute the kinematics of every body segment and to calculate the forces at all joints. The software can produce time histories of force and acceleration of body segments that are then used to predict injuries.

Each simulation represents a unique combination of seat stroking distance, impact condition, head-supported mass, and CM position. These major simulation parameters, as well as more minor ones, will be detailed in the following subsections.

5.1 Cockpit environment

The simulations were performed with the occupant seated in a crewseat modeled after those used in the AH-64 Apache. Included in each simulation were the energy attenuating characteristics of the seat and the five-point restraint system with which each seat is equipped.

5.1.1 Occupant model

The mid-size male Hybrid III manikin was used to represent the 50th percentile male aviator. The GEBOD program [4, 5] was used to generate the segment and joint data for a sitting Hybrid III dummy.

5.1.2. Energy-attenuating seat

The AH-64 crewseat was designed to attenuate energy in a vertical direction through use of a pair of inversion tubes [6]. In the simulations, the energy attenuating mechanism was modeled using a spring/damper system. The spring was used to absorb the vertical component of impact energy while the viscous damper was used to limit seat travel and prevent the seat from rebounding.

The crewseat used in the co-pilot/gunner (CPG) station of the AH-64 is designed to stroke a maximum of 25.4 cm in the vertical direction. However, accident investigations performed by the U.S. Army Safety Center have shown that in many helicopter mishaps, the travel of the seat can be hindered by obstructions resulting from fuselage deformation. Therefore, partial seat stroking distances of 2.54 centimeters (cm) and 15.24 cm were modeled in addition to the full stroking distance of 25.4 cm.

5.1.3 Restraint system

A five-point harness was included in the simulations. The harness included two waist belts, two shoulder belts, and a center tie-down strap. The inertia reels with which the shoulder belts are equipped were also modeled. Optimally functioning inertia reels were modeled by giving the shoulder belts an initial slack of 0.254 cm. This simulated the inertia reels locking within 9 milliseconds (msec) of impact.

5.2 Impact conditions

Impact conditions are dependent on variables such as helicopter velocity, attitude, and design. Due to their ability to fly vertically and horizontally, helicopters can impact terrain in a variety of attitudes. In addition, unlike older aircraft such as the UH-1, modern helicopters such as the UH-60 and AH-64 have been constructed with crashworthiness in mind. Energy-absorbing landing gear, fuselage structures, and seats have been designed with the intent to reduce the acceleration transferred to the occupants. Therefore, for identical impact orientations and velocities, the duration and shape of the acceleration profiles experienced by the occupants of a UH-60 would differ from those experienced by the occupants of a UH-1. For these reasons, there is no one typical impact condition from the occupant's perspective.

Five different impact conditions were considered in this investigation. The first three impact conditions modeled vertical impacts between the helicopter and a rigid horizontal surface. The last two conditions simulated the helicopter impacting horizontally with a rigid vertical surface [6, 7]. These impact acceleration profiles and subject orientations are presented in Figures 1 through 5.

5.3 Head-supported mass

Three HSD masses were simulated in this investigation. These masses were 0.45 kilogram (kg), 1.35 kg, and 2.70 kg. The masses correspond to weights of 4.45 Newtons (N), or 1 pound (lb), 13.35 N (3 lbs), and 26.7 N (6 lbs), respectively. This range encompassed the masses associated with HSDs currently in the U.S. Army aviation inventory.

5.4 Center of mass position

At each combination of impact condition, helmet mass, and seat stroking distance, 147 HSD CM positions were simulated. The CM positions were grouped by lateral CM position into three sets of 49 discrete x-z pairs. The first group was located in a plane 3 cm to the left of the head CM ($y = -3$ cm). The second group was clustered in the mid-sagittal plane of the occupant's head ($y = 0$ cm). The final set of 49 x-z pairs was positioned in a plane 3 cm to the right of the head CM ($y = +3$ cm). In each of the three planes, the longitudinal coordinates (x positions) of the HSD CM positions were located at –6 cm, –4 cm, –2 cm, 0 cm, +2 cm, +4 cm, and +6 cm relative to the head CM. Likewise, the axial coordinates (z positions) were placed at –6 cm, –4 cm, –2 cm, 0 cm, +2 cm, +4 cm, and +6 cm. These CM positions resulted in 147 discrete combinations of longitudinal, lateral, and axial coordinates.

All HSD CM positions are given in the ATB inertial coordinate system. This coordinate system is defined such that the positive x-axis points forward; the positive y-axis points in a direction from the occupant's left to right shoulders, and the positive z-axis points downward.

6. INJURY ASSESSMENT

6.1 Response parameters

To determine the risk of neck injury, the forces and moments acting at the Hybrid III's head/neck interface (HNI) were output from each simulation. These six response parameters included neck flexion/extension bending moment ($\pm My$), neck tension/compression force ($\pm Fz$), and neck forward/rearward shear force ($\pm Fx$). Each response parameter was generated at 1-msec intervals for a duration of 400 msec.

6.2 Inertial loadings

The magnitudes of the response parameters were influenced by the inertial loads caused by the impact accelerations and by contact forces generated during collisions between the Hybrid III head and the headrest of the seat. This investigation was concerned with only inertial loadings. Therefore, any data recorded after the first instance of head/headrest contact were excluded from the analysis. Injury assessments were based on data recorded from the beginning of the simulation to the point in time immediately before the first instance of head/headrest contact.

6.3 Assessment methodology

The assessment method used in this study was based on the peak values of each response parameter. For each of the six response parameters, the peak values of force or moment were extracted from the time history data points recorded prior to head/headrest contact. The peak values from each response parameter were normalized with respect to each parameter's injury assessment reference value (IARV) [8]. IARVs represent limits of acceptable force or moment for each response parameter. If the force or moment associated with a given response parameter remains below its IARV, the risk of injury due to that parameter is considered low. Conversely, if a given response parameter meets or exceeds its IARV, the risk of injury is considered high. Response parameters whose IARV's varied with exposure time, i.e., forward/rearward shear and axial tension and compression, were normalized using the value of the IARV corresponding to an exposure time of 0 msec. The IARVs used in this study are presented in Table 1 [8].

Table 1.
Injury assessment reference values for mid-size Hybrid III manikin [8].

Response parameter	IARV
Forward shear	3100 N
Rearward shear	3100 N
Neck tension	3300 N
Neck compression	4000 N
Neck flexion	190 N•m
Neck extension	57 N•m

Normalized response parameter (NRP) values were used to assess the risk of serious neck injury associated with each response parameter. By normalizing, the injury threshold for each response parameter became 1.0. An NRP value of less than 1.0 indicated that the peak value of the response parameter in question did not exceed its given IARV. Thus, the risk of serious neck injury associated with that response parameter was considered low. An NRP value of 1.0 or greater signified that the maximum value of the particular response parameter met or exceeded its IARV. Thus, the response parameter posed a high risk of serious neck injury.

Acceptable combinations of HSD mass and CM placement were determined for each simulation. If none of the six NRP values reached or exceeded the threshold value of 1.0, the combination of HSD mass and CM placement associated with the particular simulation was judged to be acceptable. Otherwise, the combination of HSD mass and CM placement was considered unacceptable.

The acceptable combinations of HSD mass and CM position associated with each simulation were grouped into regions of acceptable longitudinal and axial (x-z) CM placement for each HSD mass, lateral CM position, seat stroking distance, and impact condition.

7. RESULTS

Regions of acceptable x-z CM location were determined for each lateral CM position, seat stroking distance, and impact condition. However, in the interest of brevity, only representative cases will be presented. These examples are illustrative of the relationship between HSD mass and x-z CM position, as well as the dependency of this relationship on lateral CM position and seat stroking distance. A more complete presentation of the results for each lateral CM position, seat stroking distance, and impact condition is available elsewhere [9].

The shaded areas of Tables 2 and 3 show the acceptable x-z CM positions within the mid-sagittal plane for the three HSD masses and all five impact conditions at a seat stroking distance of 2.54 cm. In addition, the shaded areas of Tables 4 and 5 show the regions of acceptable x-z CM placement within the three lateral CM planes for impact conditions 4 and 5, respectively, at a 15.24-cm seat stroking distance. Furthermore, Tables 6 and 7 depict the regions of acceptable x-z CM placement within the mid-sagittal plane at the three seat stroking distances for impact conditions 2 and 4, respectively.

8. DISCUSSION

Most aircrew helmets in the U.S. Army inventory have their CM positions within the mid-sagittal plane of the head. For this reason, discussions of the relationship between HSD mass and CM placement will be limited to results of simulations conducted within the mid-sagittal plane at a 2.54-cm seat stroking distance. Furthermore, the effect of placing lateral CM positions off the mid-sagittal plane will be presented for both symmetric and asymmetric impact conditions. In addition, the effects of seat stroking distance on both vertical and horizontal impact conditions will be discussed using two illustrative examples.

8.1 HSD mass and CM position

Tables 2 and 3 show that acceptable combinations of HSD mass and x-z CM locations can be found for most impact conditions. In the case of impact condition 1, acceptable x-z CM locations were determined for each of the three HSD masses. However, the number of acceptable x-z CM locations diminished from 49 at a HSD mass of 0.45 kg to 18 at a HSD mass of 2.70 kg. As for impact condition 2, only three acceptable x-z CM locations could be determined for a HSD mass of 0.45 kg. For the other two masses, the number of acceptable x-z CM locations diminished to zero. Similarly, for impact condition 3, no acceptable x-z CM positions were found for any of the HSD masses. Acceptable x-z CM locations were determined for HSD masses of 0.45 kg and 1.35 kg when impact conditions 4 and 5 were considered. As with the results of impact condition 1, the number of acceptable x-z CM positions was reduced with increasing HSD mass. Similar trends were found for the other combinations of lateral CM position and seat stroking distance.

It is also interesting to note that as HSD mass grows larger, acceptable x-z CM positions begin to cluster to the rear of and below the head CM (Tables 2 and 3). This trend is most obvious when impact conditions 1 and 4 are considered. For impact condition 1, when HSD mass was increased from 0.45 to 2.70 kg, the region of acceptable x-z CM positions reduced from one that encompassed all 49 CM positions to a trapezoidal shaped region spanning from x = –6 to –2 cm and from z = +6 to –4 cm. In impact condition 4, at an HSD mass of 0.45 kg, the region of acceptable x-z CM positions encompassed all 49 CM positions. When HSD mass was increased to 1.35 kg, most of the acceptable x-z CM positions became clustered in a region spanning from x = –6 to –2 cm and from z = +6 to +2 cm. Three other acceptable x-z combinations occurred at a z position of +2 cm and x positions of 0, +2, and +4 cm. Again, similar trends were found for the other combinations of lateral CM position and seat stroking distance.

8.2 Effects of lateral CM position

Tables 4 and 5 illustrate the effects of positioning the HSD CM off the mid-sagittal plane on acceptable combinations of HSD mass and x-z CM position for impact conditions 4 and 5. Impact condition 4 is an asymmetric impact condition; i.e., the inertial load does not act strictly within the occupant's mid-sagittal plane. This is caused by the 30° yaw condition associated with this crash scenario. Impact condition 5 is symmetric, in that there are no yaw, pitch or roll conditions associated with this impact condition that would cause the load to be applied outside the mid-sagittal plane.

The results presented in Tables 4 and 5 show that lateral CM position has no effect on the acceptable HSD mass. In the case of impact condition 4, HSD masses of up to 1.35 kg could be worn no matter which lateral CM plane their longitudinal and axial CM positions are placed within (Table 4). In addition, Table 5 shows that an acceptable HSD mass of up to 1.35 kg could be worn within each lateral CM plane. However, for both impact conditions, x-z CM placement is extremely limited for the 1.35-kg HSD mass.

Tables 4 and 5 also show that placing the HSD CM position off the mid-sagittal plane reduces the number of acceptable x-z CM positions for each HSD mass. For example, consider the cases involving a 1.35-cm HSD mass and impact condition 4 (Table 4). Comparisons between the results of placing the lateral CM position at +3 cm and coincident with the mid-sagittal plane show that placing the lateral CM position at +3 cm reduces the number of acceptable x-z CM positions (Table 4). Consider now the results for the same HSD mass and impact condition 5 (Table 5). Placing CM positions to either side of the mid-sagittal plane reduces the number of acceptable x-z CM positions when compared with results involving CM positions within the mid-sagittal plane.

There is an exception, however, in the case of impact condition 4 and an HSD mass of 1.35 kg (Table 4). Placing the lateral CM position at –3 cm increases the number of acceptable x-z CM positions compared to a lateral CM coincident with the mid-sagittal plane. However, to date, no statistical analysis has been performed on these data. Therefore, it is unknown whether the increased number of acceptable x-z CM positions is statistically significant.

8.3 Effects of seat-stroking distance

Tables 6 and 7 illustrate the effect of seat stroking distance on the relationship between HSD mass and x-z CM position for both a vertical impact condition (condition 2) and a horizontal impact condition (condition 4), respectively.

In the case of a vertical impact condition, increased seat stroking distance allows for greater flexibility in the selection of HSD mass and x-z CM placement (Table 6). At a seat stroking distance of 2.54 cm, the maximum HSD mass that could be worn by an aviator was 0.45 kg, but by increasing the distance that the seat is allowed to travel to 15.24 or 25.4 cm, the allowable HSD mass increases to 2.70 kg. Furthermore, acceptable regions of x-z CM position grow larger as seat stroking distance increases. Take, for example, an HSD mass of 1.35 kg. With the stroking distance limited to 2.54 cm, this HSD mass could not be positioned anywhere within the mid-sagittal plane without posing a serious risk of neck injury. However, the number of acceptable x-z CM positions grows to 15 with a stroking distance of 15.24 cm and to 49 when the seat is allowed to stroke 25.4 cm. The results of impact conditions 1 and 3 exhibit similar trends.

The results of impact condition 5 show that seat stroking distance has no effect on acceptable HSD mass and x-z CM placement when horizontal impact conditions are considered. Allowable HSD mass does not increase with additional seat stroking distance in the vertical direction (Table 7). In addition, regions of acceptable x-z CM position remain unchanged from one seat stroking distance to the next. The results of impact condition 4 show a similar trend. This lack of influence can be explained by the fact that the energy attenuating seats modeled in this study were designed to dissipate vertical rather than horizontal energy.

8.4. Study limitations

As only the 50th percentile male aviator was simulated, results will be different for other aviator sizes, particularly for small size females. Also, note that the results presented herein are based purely on neck injury mechanisms and do not take into account user acceptance or fatigue issues. Furthermore, no statistical analysis has been performed on the data presented in this paper. Statistical analysis should be performed in order to determine the significance of each parameter considered in this study. Finally, the results presented should not be extrapolated to HSD masses or CM positions other than those simulated.

9. CONCLUSIONS

In this study, mathematical simulations were performed in order to determine acceptable regions of x-z CM position for three HSD masses and five impact conditions. In addition, the effects of lateral CM placement and seat stroking distance on these acceptable regions were investigated. From the results of this study, the following conclusions were drawn:

- Acceptable HSD mass and x-z CM locations are dependent on impact condition, particularly acceleration pulse magnitude, direction, and shape.

- The number of acceptable x-z CM positions diminishes with increased HSD mass.
- In most cases, as HSD mass increases, the acceptable x-z CM locations cluster below and to the rear of the head CM.
- For vertical impact conditions, larger seat stroking distances allow for increased acceptable HSD masses and a greater number of acceptable x-z CM locations.
- In most cases, placing the lateral CM position off the mid-sagittal plane reduces the number of acceptable x-z CM locations.

10. RECOMMENDATIONS

The five impact conditions modeled in this study represented a cross section of the types of impacts on record. However, future efforts should include more crash scenarios to better define the effects of impact condition on acceptable combinations of HSD mass and CM placement. Also, experience has shown that inertia reels do not always work at optimal efficiency [10]. Future studies should investigate the effect of inertia reel performance on acceptable HSD mass and CM placement. Finally, the trends shown in the results of these simulations should be validated using full-scale manikins and sled tests.

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12. ACKNOWLEDGEMENTS

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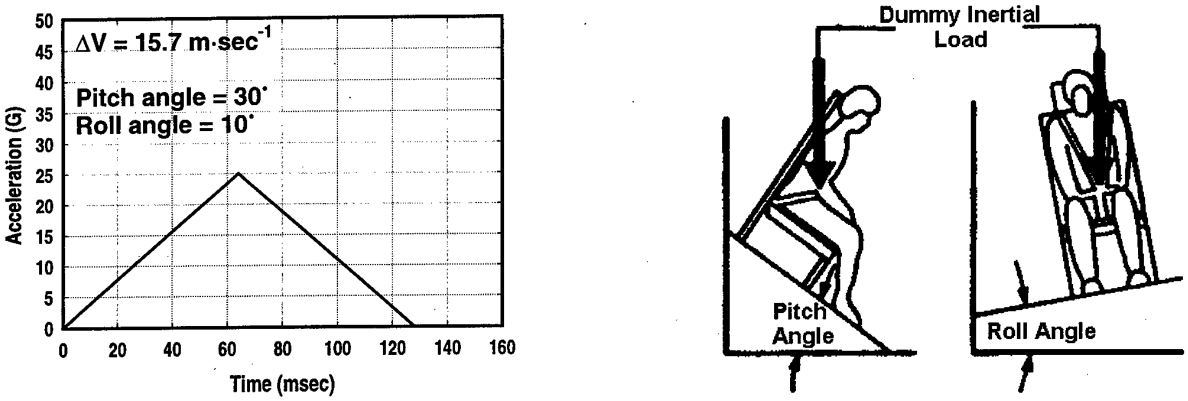

Figure 1. Acceleration pulse and subject orientation modeled in impact condition 1.

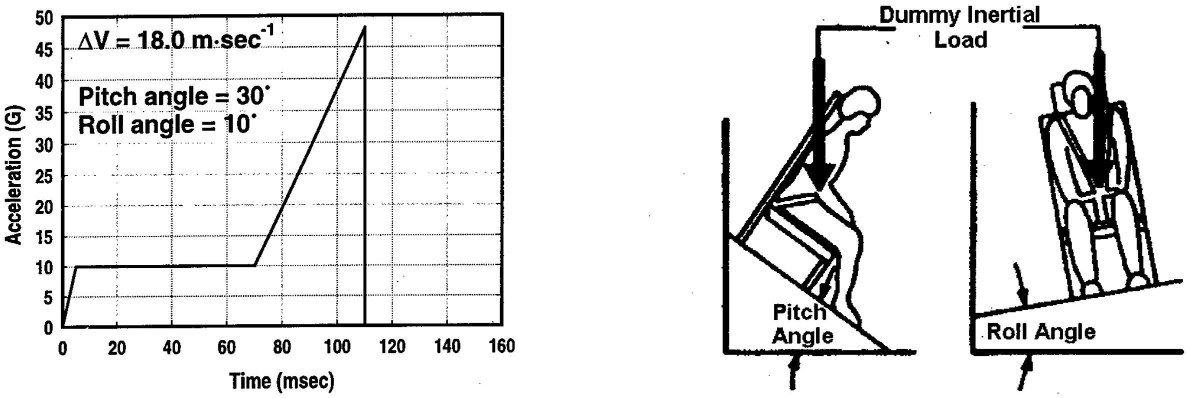

Figure 2. Acceleration pulse and subject orientation modeled in impact condition 2.

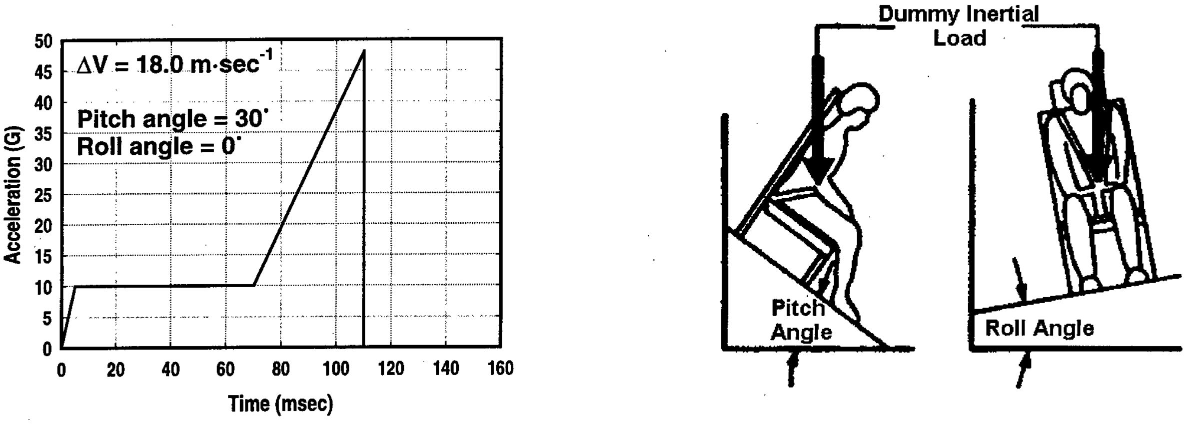

Figure 3. Acceleration pulse and subject orientation modeled in impact condition 3.

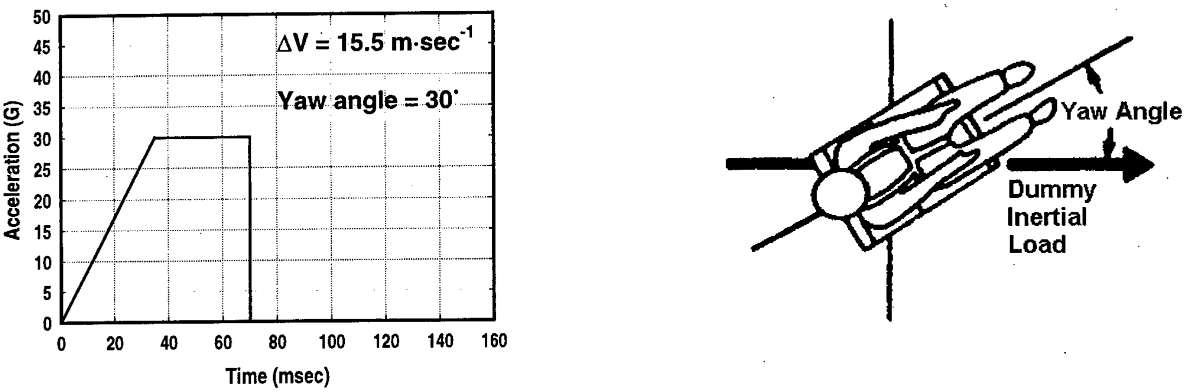

Figure 4. Acceleration pulse and subject orientation modeled in impact condition 4.

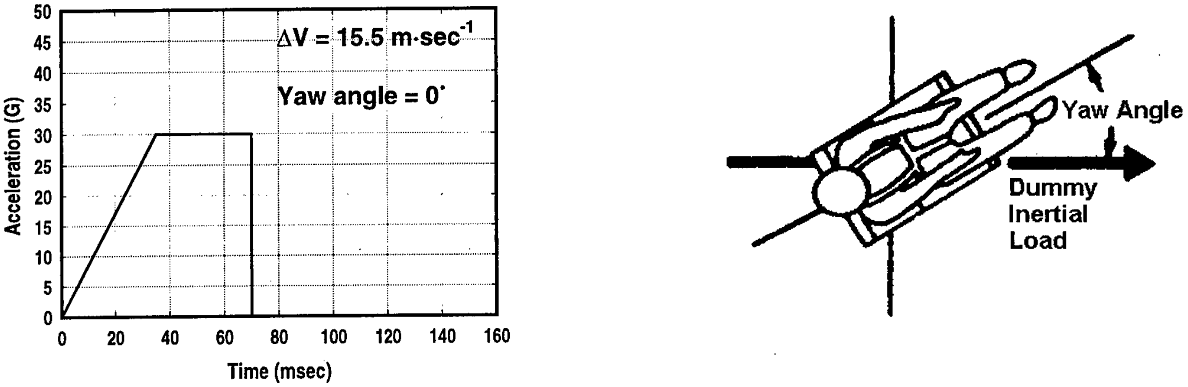

Figure 5. Acceleration pulse and subject orientation modeled in impact condition 5.

Table 2.
Number of failures at 49 HSD CM locations for the three HSD masses and impact conditions 1, 2, and 3.
(Mid-sagittal plane, 2.54-cm seat stroke)

	Impact condition	1							2							3						
	X position (cm)	−6	−4	−2	0	+2	+4	+6	−6	−4	−2	0	+2	+4	+6	−6	−4	−2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)																					
0.45	−6	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3	3	3	3	3	3	3
	−4	0	0	0	0	0	0	0	1	1	1	1	1	1	1	3	3	3	3	3	3	3
	−2	0	0	0	0	0	0	0	1	2	1	1	1	1	1	2	2	3	3	3	3	3
	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	3	3	3	3
	+2	0	0	0	0	0	0	0	1	1	1	1	2	1	1	2	2	2	2	3	3	3
	+4	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	2	2	2	2	3	3
	+6	0	0	0	0	0	0	0	1	1	1	1	2	1	1	3	3	2	2	2	2	3
1.35	−6	0	0	0	0	0	1	1	3	3	3	3	3	2	3	3	3	3	3	3	3	3
	−4	0	0	0	0	0	1	1	3	3	3	3	3	2	2	3	3	3	3	3	3	3
	−2	0	0	0	0	0	1	1	3	3	3	3	3	2	2	3	3	3	3	3	3	3
	0	0	0	0	0	0	1	1	3	3	3	3	3	2	2	3	3	3	3	3	3	3
	+2	0	0	0	0	0	1	1	3	3	3	2	2	2	2	3	3	3	3	3	3	3
	+4	0	0	0	0	0	1	1	3	3	2	2	2	2	2	2	3	3	3	3	3	3
	+6	0	0	0	0	0	1	1	2	2	2	2	2	2	2	2	2	3	3	4	3	3
2.70	−6	0	1	1	1	1	2	2	3	3	3	3	4	4	4	3	3	3	3	4	4	4
	−4	0	0	0	1	2	2	2	3	3	3	3	4	4	4	3	3	3	3	4	4	4
	−2	0	0	0	1	1	2	2	3	3	3	4	4	4	4	3	3	3	3	4	4	4
	0	0	0	0	1	1	2	2	3	3	3	4	4	4	4	3	3	3	3	4	4	4
	+2	0	0	0	1	1	1	2	3	3	3	4	4	4	4	3	3	3	4	4	4	4
	+4	0	0	0	1	1	1	2	3	3	3	4	4	4	4	3	3	3	4	4	4	4
	+6	0	0	1	1	1	1	1	3	3	4	4	4	4	4	3	3	3	4	4	4	4

Table 3.
Number of failures at 49 HSD CM locations for the three HSD masses and impact conditions 4 and 5.
(Mid-sagittal plane, 2.54-cm seat stroke)

	Impact condition	4							5						
	X position (cm)	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)														
0.45	–6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.35	–6	1	1	1	1	1	1	1	1	1	1	1	1	2	2
	–4	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	–2	1	1	1	1	1	1	1	1	1	1	2	2	2	2
	0	1	1	1	1	1	1	2	1	1	1	1	2	2	2
	+2	0	1	0	0	0	0	1	1	1	1	2	2	2	2
	+4	0	0	0	1	1	1	1	0	1	0	0	1	2	2
	+6	1	0	0	1	1	1	1	0	0	0	0	1	1	1
2.70	–6	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	–4	1	1	1	1	1	1	1	1	1	1	2	2	2	2
	–2	1	1	1	1	1	1	1	1	1	1	2	2	2	2
	0	1	1	1	1	1	2	2	1	1	1	2	2	2	2
	+2	1	1	1	2	2	2	2	1	1	1	2	2	2	2
	+4	1	2	2	2	2	2	2	1	1	2	2	2	2	2
	+6	2	2	2	2	2	2	2	1	2	2	2	2	2	2

Table 4.
Number of failures at 49 HSD CM locations for the three HSD masses and three lateral CM planes.
(Impact condition 4, 15.24-cm seat stroke)

	Y position (cm)	–3							0							+3						
	X position (cm)	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)																					
0.45	–6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.35	–6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	2	2
	+2	1	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	0	1	1	2	2
	+4	0	0	0	0	0	0	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1
	+6	0	0	1	1	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	1	1
2.70	–6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
	–2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	2	2
	+2	1	1	1	1	1	1	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2
	+4	1	1	1	2	2	2	2	1	2	2	2	2	2	2	1	2	2	2	2	2	2
	+6	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 5.
Number of failures at 49 HSD CM locations for the three HSD masses and three lateral CM planes.
(Impact condition 5, 15.24-cm seat stroke)

	Y position (cm)	–3							0							+3						
	X position (cm)	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)																					
0.45	–6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.35	–6	1	1	1	1	2	2	2	1	1	1	1	1	2	2	1	1	1	1	2	2	2
	–4	1	1	1	1	2	2	2	1	1	1	1	2	2	2	1	1	1	1	2	2	2
	–2	1	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1	1	2	2	2	2
	0	1	1	1	2	2	2	2	1	1	1	1	2	2	2	1	1	1	2	2	2	2
	+2	1	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1	1	2	2	2	2
	+4	1	1	1	1	1	2	2	0	1	0	0	1	2	2	1	1	1	1	1	2	2
	+6	0	0	0	1	1	1	1	0	0	0	0	1	1	1	0	0	0	1	1	1	1
2.70	–6	1	1	1	2	2	2	2	1	1	1	1	2	2	2	1	1	1	2	2	2	2
	–4	1	1	2	2	2	2	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2
	–2	1	1	2	2	2	2	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2
	0	1	1	2	2	2	2	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2
	+2	1	1	2	2	2	2	2	1	1	1	2	2	2	2	1	1	2	2	2	2	2
	+4	1	1	2	2	2	2	2	1	1	2	2	2	2	2	1	1	2	2	2	2	2
	+6	1	2	2	2	2	2	2	1	2	2	2	2	2	2	1	2	2	2	2	2	2

Table 6.
Number of failures at 49 HSD CM locations for the three HSD masses and three seat stroking distances.
(Mid-sagittal plane, impact condition 2)

	Stroking distance (cm)	2.54							15.24							25.4						
	X position (cm)	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)																					
0.45	–6	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	–4	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
	–2	1	2	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0
	+2	1	1	1	1	2	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	+4	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	+6	1	1	1	1	2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
1.35	–6	3	3	3	3	3	2	3	0	0	0	0	1	1	1	0	0	0	0	0	0	0
	–4	3	3	3	3	3	2	2	0	0	0	0	1	1	1	0	0	0	0	0	0	0
	–2	3	3	3	3	3	2	2	0	0	0	1	1	1	1	0	0	0	0	0	0	0
	0	3	3	3	3	3	2	2	0	0	1	1	1	1	1	0	0	0	0	0	0	0
	+2	3	3	3	2	2	2	2	0	1	1	1	1	1	1	0	0	0	0	0	0	0
	+4	3	3	2	2	2	2	2	0	1	1	1	1	1	1	0	0	0	0	0	0	0
	+6	2	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	0
2.70	–6	3	3	3	3	4	4	4	1	1	1	2	2	2	2	0	0	0	0	0	0	0
	–4	3	3	3	3	4	4	4	1	1	1	2	2	2	3	0	0	0	0	0	0	0
	–2	3	3	3	4	4	4	4	0	0	0	1	1	1	1	0	0	0	0	0	0	0
	0	3	3	3	4	4	4	4	0	0	0	1	1	1	1	0	0	0	0	0	0	0
	+2	3	3	3	4	4	4	4	1	0	0	1	1	1	1	0	0	0	0	0	0	0
	+4	3	3	3	4	4	4	4	1	1	1	1	1	1	1	0	0	0	0	0	0	0
	+6	3	3	4	4	4	4	4	0	1	1	1	1	1	1	0	0	0	0	0	0	0

Table 7.
Number of failures at 49 HSD CM locations for the three HSD masses and three seat stroking distances.
(Mid-sagittal plane, impact condition 4)

	Stroking distance (cm)	2.54							15.24							25.4						
	X position (cm)	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6	–6	–4	–2	0	+2	+4	+6
HSD mass (kg)	Z position (cm)																					
0.45	–6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	–2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	+6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.35	–6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	2
	+2	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1
	+4	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1
	+6	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1
2.70	–6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	–2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	0	1	1	1	1	1	2	2	1	1	1	1	1	2	2	1	1	1	1	1	2	2
	+2	1	1	1	2	2	2	2	1	1	1	2	2	2	2	1	1	1	2	2	2	2
	+4	1	2	2	2	2	2	2	1	2	2	2	2	2	2	1	2	2	2	2	2	2
	+6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

EXTERNAL POSITION LIGHTING EFFECTS ON NIGHT VISION GOGGLE PERFORMANCE

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SUMMARY

Army aviation depends heavily on image intensification (I^2) devices to extend operations into the night. Such devices are light amplification systems that adjust their amplification factor (gain) according to the level of ambient illumination. However, these night vision goggles (NVGs) are unable to distinguish between light originating from the exterior scene and light originating from either instruments inside the cockpit or lights mounted to the aircraft. Consequently, the NVG may lower gain unnecessarily, and in doing so, degrade image quality. The compatibility problem is most apparent when light in the red part of the spectrum is present. This is the problem with the UH-1's red lateral position lights. These lights flood into the cockpit, affecting NVG performance – the presence of fog and other weather heightens this effect. A solution to this problem has been to mask appropriate upper and lower portions of the two red position lights, thereby reducing the NVG degradation. However, this solution appeared to conflict with Federal Aviation Regulation (FAR) lighting intensity distributions for each of the two lights. We calculated that the FAR could be satisfied at a distance of one rotor disk radius by masking 82 degrees of each respective position light (leaving 98 degrees unmasked). Objective video recordings and test pilots' subjective observations indicate a significant reduction in NVG degradation with the 82-degree masking scheme as compared to operations with unmasked position lights. The 82-degree masking scheme meets the FAR requirements while reducing simultaneously the performance degradation of the NVG devices. We will show a composite video with observations at the meeting.

INTRODUCTION

In the 1970s, the Department of Defense (DoD) decided to improve the Army's ability to fight in low light conditions. In compliance with that decision, the U.S. Army borrowed image intensification (I^2) technology from the National Aeronautics and Space Administration (NASA). However, since NASA originally developed this technology to allow astronauts to see on the dark side of the moon, modifications were necessary given the requirements of the Army environment. The first image intensifiers, now called Night Vision Devices (NVDs), began to appear on the ground in use by tankers, the infantry, and other units. Army aviation, as an integral part of the combined arms team, developed the necessary tactics and equipment to allow Army aircraft to train and fight effectively at night. This I^2 technology has greatly enhanced U.S. Army aviation operations since its acceptance into Army aviation's rotary-wing program, and today's aviation commanders depend heavily on these devices to extend their operations into the night.

Notwithstanding, NVDs have their limitations. For instance, aircraft interior and exterior lighting can cause problems due to the I^2 device's inability to distinguish between light originating from the outside scene and light originating from other sources within its field-of-view (FOV) (i.e., cockpit lighting, aircraft position lighting, and other auxiliary lighting). In response to such lights, these devices adjust their amplification factor (gain) downward according to the level of ambient illumination, and in doing so, can cause degradation in the resulting image, to the extent that visual information may be lost.

Early in the process of testing and training on NVDs, aviators found that lights having wavelengths in the red and near-infrared degraded the goggle's effectiveness more so than other lights. As most cockpits used red lights in order to avoid adversely affecting night vision adaptation, corrective action became necessary. The Army conducted various studies to develop alternatives [1,2,3] that led to the modification of aircraft cockpits to replace the existing red lighting with NVD compatible blue-green lighting. This lighting does not significantly reduce the aviator's natural night adaptation, nor does it interfere with NVDs since the lights emit in a part of the spectrum not amplified by NVDs[1]. The Army developed Maintenance Work Orders (MWOs) to retrofit existing aircraft cockpits with the modified lighting, and to date, the majority of the fleet has been modified. MIL-L-85762A establishes night vision imaging systems (NVIS) compatibility requirements for cockpit/interior lighting [4].

However, in addition to cockpit lights, aircraft also use exterior lights (i.e., anticollision lights, rotating beacons, landing lights, search lights, and position lights). MIL-L-6503H is the primary exterior lighting specification used by the Army [5]. This latter specification has not been revised to take into account present mission and training requirements in the I^2 environment. Exterior lighting compatibility problems have been recognized, but only limited technical evaluations have been performed. The Department of the Navy recognized exterior lighting compatibility problems during the Research, Development, Test, and Evaluation (RDT&E) of the A-12 program [6] and developed test procedures for evaluating lighting compatibility in an effort to integrate exterior lighting for I^2 operations. In 1990, the U.S. Army Aviation Training

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[1] Class A third generation aviator's night vision imaging systems (ANVIS), with the 625 nm minus-blue filter, are highly responsive to light emitted through red and clear filters but not to light emitted through green filters. Second generation systems are responsive to light transmitted through red, clear, and green filters due to their wide sensitivity range extending across the visible spectrum.

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Brigade (ATB) and the U.S. Army Aeromedical Research Laboratory (USAARL) surveyed Army aviation field units to identify problems experienced with helicopter-mounted exterior lighting during NVD operations [7]. The UH-1 results showed that the left (red) lateral position light and the rear (white) tail position light were too bright for formation flight. The right (green) lateral position light was not a problem. Additionally, the left side light put the right side of the aircraft in a shadow, and the red light floods into the cockpit, degrading I^2 performance significantly; the presence of fog and other weather heightens this effect. In response to exterior lighting compatibility problems, the Army modified searchlights and landing lights with "pink light" filters and low-wattage bulbs to make them compatible with NVDs. However, anticollision lights, rotating beacon, and position lights continue to present NVD-related problems.

In attempts to minimize the degradation of I^2 performance, modifications have been made to position lighting in Army aviation tactical and training environments. Two fielded approaches to the position lighting problem are operating position lights in the dim mode and partial masking. Dim mode operation of position lighting on Army helicopters is available by using a switch to reduce the intensity of all exterior lighting. However, Snook, et al. show aircraft position lights in the dim mode fail to meet Federal Aviation Administration (FAA) illumination requirements [7]. Masking configurations were developed to decrease the angular distribution of position lighting without decreasing intensity. This partial masking modifies existing aircraft by taping and or painting the glass dome of the position lights, thus cropping the pattern of light emitted. The masking is designed to cover the position lights only at specific areas where emitted light may enter the crew compartment or distract aircraft in formation. Presently, only one MWO authorizes modifications to meet requirements of night formation flight, and it applies only to the UH-1, not all Army aircraft [8].

While partial masking of position lights reduced degradation of I^2 imagery, this modified lighting appeared to conflict with requirements established by the FAA for light distribution and intensities. However, Army aircraft had been flying with masked red position lights, under a FAA sanctioned waiver [9], which allowed U.S. Army tactical helicopters conducting NVD flight training to fly without lighted position lights under certain restrictions. The exemption expired on December 31, 1996 and a subsequent aviation safety-action message directed the mandatory inspection and removal of any materials that obscured normal operation of UH-1 position lights [10].

The Army opted not to request continuing extensions of the exception that waived the minimum lighting requirements. Under such a waiver, Army and civilian aviators were still being put into preventable dangers. Aircraft operating with inadequate exterior lighting, or lighting incompatible with NVDs, were at a greater risk for mishap. Thus, the ideal solution was to develop aircraft exterior lighting that complied with FAA requirements and did not degrade NVD performance. This solution would cancel the need for another FAA waiver and would enhance civilian and military aviation safety.

FAA Lighting Regulations and Exemption 3946D

The FAA requires that Army aircraft using the National Airspace System (NAS) meet specific criteria for exterior lighting angular distribution and intensities sufficient to provide aircraft position information. On the UH-1 utility helicopter, these exterior lights include two red lateral position lights on the left side of the aircraft and two green lateral position lights on the right side. Federal Aviation Regulations (FARs) (paragraphs 1387-1393 of Parts 27 and 29) address angular intensity distributions for exterior lights [11], and specifications in MIL-L-6503H are based upon these requirements [5]. In general, the specifications state that position lights shall provide their greatest intensities in the forward and rear directions of the aircraft during flight (Figure 1). However, these requirements were developed prior to the introduction of I^2 devices in aviation and were based on unaided (naked eye) viewing. As outline previously, in an I^2 environment, the spectral distribution and intensity requirements for aircraft exterior lighting can be detrimental and result in hazardous flying conditions.

FAR Part 91 and Army Regulation (AR) 95-1 require position lights to be on at all times during periods of darkness [11, 12]. Additionally, in accordance with AR 95-1 and AR 95-2, U. S. Army aircraft operating in the NAS must meet the requirements set forth in the FARs unless the FAA grants an exemption [12,13]. AR 95-2, paragraph 9-2, stipulates the limited exceptions for NVD flight in Army aircraft. As mentioned previously, the FAA granted an exemption that allowed U.S. Army tactical helicopters conducting NVD flight training to fly without lighted position lights under certain restrictions [9]. Specifically, the exemption permitted lights-out operations in certain phases of NVD device training within well-defined and controlled areas when two or more helicopters were involved, and then only with advanced coordination with other nonparticipating parties. For all other areas in the NAS, authorization was given for position lights to be on dim at altitudes up to 500 feet (152.5 m) above ground level (AGL) provided the aircraft was not within 5 nautical miles of any public use airport. Problems arose when aided formation flights, operating with modified lighting (masked or dimmed lighting), transitioned from military airfields to training areas at altitudes above 500 feet AGL in compliance with local noise abatement practices. In these situations, there were concerns that unaided civilian traffic could not visually acquire and appropriately respond to aircraft operating with modified lighting configurations.

To be proactive to this problem, USAARL conducted a study to document the intensity distributions of several masking schemes [7]. Included was the current (until December 1996) masking scheme of blackening the lower half of the upper red position light and the upper half of the lower red position light. Data from this study showed, as expected, that each position light did not individually meet the FAA regulation. However, given that the UH-1 has two lateral position lights per side, USAARL set out in March 1997 to determine if the presence of the two position lights did not, together, meet the FAR, since the FAR was based on a single lateral position light per side. This paper reports the results of the 1997 study. In addition to the "two light" question, this study helps determine actual levels of ANVIS degradation by exterior lighting, evaluates potential solutions to affordably modify the fleet to eliminate NVD degradation in compliance with the FAA regulations, and recommends the safest and most cost effective solution. The recommendations herein should reduce or eliminate liability exposure due to questionable operations within the NAS.

METHODS and RESULTS

We used a two-phase approach to investigate these issues. The first phase was a limited investigation of position light effects on NVD performance inside the cockpit (endogenous effects) as well as the effects on other pilots outside the cockpit (exogenous effects). The second phase addressed the problem of position light modifications and FAR compliance.

Endogenous effects of masked and dimmed lights

A UH-1 was positioned heading north in a relatively dark corner of Lowe Army Airfield, Fort Rucker, Alabama. After the end of nautical twilight, video recordings from the left seat were made using a single ANVIS tube optically coupled with a commercial camcorder. The FOV for the camcorder with the intensifier tube was approximately 45 degrees, showing the 40-degree circular intensifier image. The aircraft position light combinations were bright and dim, masked and unmasked, and with and without fuselage lights and rotating beacon.

An Air Force Tri-bar resolution chart was positioned 66 and 178 feet (20.13 and 54.29 m) from the left seat observer, perpendicular to the aircraft alignment outside the left window. At 66 feet, the red position lights increased the luminance and resolution of the Air Force chart, but the trees in the background were barely visible in the bright mode. The white fuselage lights and rotating beacon had negligible effects. The green position lights did not affect ANVIS performance[2]. All observers considered the decrease in visibility in the left hemisphere around the aircraft as very undesirable – decreasing both depth perception and visual acuity. They also reported excessive glare inside the cockpit, on the upper windscreen, and left cargo door. Masking the position lights and operating in the dim mode significantly improved visibility. However, comparisons between these two alternatives showed that the dim mode improved visibility much more than masking. When the chart was moved out to 178 feet, all observers could recognize the largest bar patterns for this field chart (-6,1) with 20/40 resolution. Black and white rectangles (12x16 inches; 30.5x40.6 cm) were taped to the back of the resolution chart. Even at that distance, the illumination increased the apparent brightness of the rectangles, showing the standard field resolution charts are too small to show the effects from the red position light.

Endogenous effects also were recorded in flight at Runkle Army Helicopter Stagefield, under 38 percent moon illumination[3]. The primary areas of interest for the flight observations were the altitude-related effects during take-off and landings. In flight, bright unmasked position lights did not interfere with visibility at low level altitudes between 50 and 100 feet (15 to 30 m) above the trees. However, reflections seen in the windscreen interfered with outside vision and were distracting. In this mode, a dimming of the horizon from activation of the automatic brightness control (ABC) was apparent within 25 feet of the ground and progressively worsened with decreasing altitudes. Pilots stated that in this mode, hovering, take-off, and landing would be unsafe. In the bright masked mode, pilots noted a slight dimming of the horizon, but only within a few feet of the ground. Pilots considered this decrement acceptable. In the dim mode, both masked and unmasked, outside vision with ANVIS was acceptable, but the masked lights improved outside and inside vision more by comparison.

In addition to these observations, USAAVNC had their instructor pilots fill out surveys after each NVG flight for a month to document their impressions of the various configurations. One concise and insightful response is quoted below:

> "...Below 100 feet the [unmasked] red position lights over-powered the IR band pass filter to the 10-12 O'clock position. This bright line of light continually moved back and forth with each minor heading change and became annoying. Out of the left side, the very high humidity was sensed by the NVGs automatic brightness control circuits and detail, texture, and contrast of the trees and ground was diminished. In these conditions, or worse, I would be hesitant to turn left (a normal instinct) to find a quick landing spot due to a precautionary landing. To the right front, the visual scene was normal. Dealing with two different visual environments while teaching IERW [initial entry rotary wing] students NVG flight pushes our safety factor. ... [Masked] the 82-degree[4] and 90-degree configurations were not noticeably different from each other. Both significantly reduce the effects noted above and greatly improve visibility outside the cockpit." [anonymous]

Exogenous effects of masked and dimmed lights

We used three UH-1 aircraft in flight to document detection and recognition of exterior lighting arrangements and to demonstrate the effects of modified configurations on other pilots outside the cockpit (i.e., multi-ship

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[2] A senior UH-1 instructor pilot noted that unaided vision was decreased when the green lights were not masked.

[3] Without moon illumination, these reported effects from the position lights would be worse, and a little better with higher moon illumination.

[4] See FAA Compliance section.

operations). Simultaneous video recordings were made using a low light black and white charged-coupled device (CCD) video camera (which approximates the sensitivity of the human eye) and a commercial camcorder optically coupled with a single ANVIS tube. To simulate the eye response, a near infrared-attenuating filter was placed on the CCD camera in an attempt to match the apparent intensity of the green and red position lights. The focal length on the CCD camera was selected to produce approximately 20/20 vision for the viewing distance when viewed on a good monitor. The field of view for the CCD camera was approximately 6.5 degrees horizontally and the FOV for the camcorder was as described previously. The recordings were made from the walkway on the control tower of Lowe Army Airfield. The walkway is approximately 50 feet (15 m) AGL. Moon illumination was 4 percent with an altitude of 8 degrees above the horizon. The sky was overcast with visibility greater than 7 miles (11 km). Position light configurations were bright and dim, with and without the white fuselage lights. One aircraft had position lights masked as previously approved for NVD flight. The anti-collision lights were activated at all times.

Three UH-1 aircraft that were scheduled for NVG training executed prearranged take-offs and multiple passes at an altitude level with the control tower using an extended right traffic pattern. The traffic patterns were south of the tower with the aircraft pass closest to the tower when traveling from west to east. After the passes, the aircraft departed the area using either the south or north corridors. The UH-1s were easily visible for miles from all angles and under all viewing conditions. However, the white fuselage lights tended to mask the color of the red and green position lights in all configurations. The red and green position lights without the white fuselage lights, even when masked and in the dim mode, could be distinguished at comparable or greater distances than in the bright mode, unmasked, when the white fuselage lights were activated. Additionally, the anti-collision lights tended to mask position lights with increasing viewing distances.

FAA Regulatory Compliance

The UH-1 uses Whelen Engineering W1285 PR & PG position lights with Grimes Aerospace Corporation type III reflector bulbs rated for 28 volts direct current (VDC) manufactured to specifications in MIL-L-6363F [14]. These lights conform to Part 21 of the FAR, and are certified under FAA TSO-C30b [11,15]. Thus, the issue of compliance in the UH-1 does not concern the lights, but rather the configuration and placement of these lights. FARs, Parts 27 and 29, specify that forward position lights be spaced as far apart laterally as practicable; for fixed wing aircraft this is achieved by placing one position light on each wingtip [11]. Modifications are necessary for rotary-wing aircraft to meet the intent of the regulations. On helicopters, the greatest lateral distances are across the midsection of the fuselage since there are no wings. In which case, design specifications allow supplemental position lights to be installed in any location necessary to meet the minimum light distribution requirements. The specifications also allow shields to be installed to eliminate pilot annoyances[5] [16, 17, 18]. The UH-1 has two position lights on each side providing redundant intensity distribution within the 360-degree sphere around the aircraft. This begs the question, "Does the previously approved masking scheme of blackening the bottom half of the upper red position light and the top half of the lower red position light meet the angular lighting intensity requirements of the FAR?"

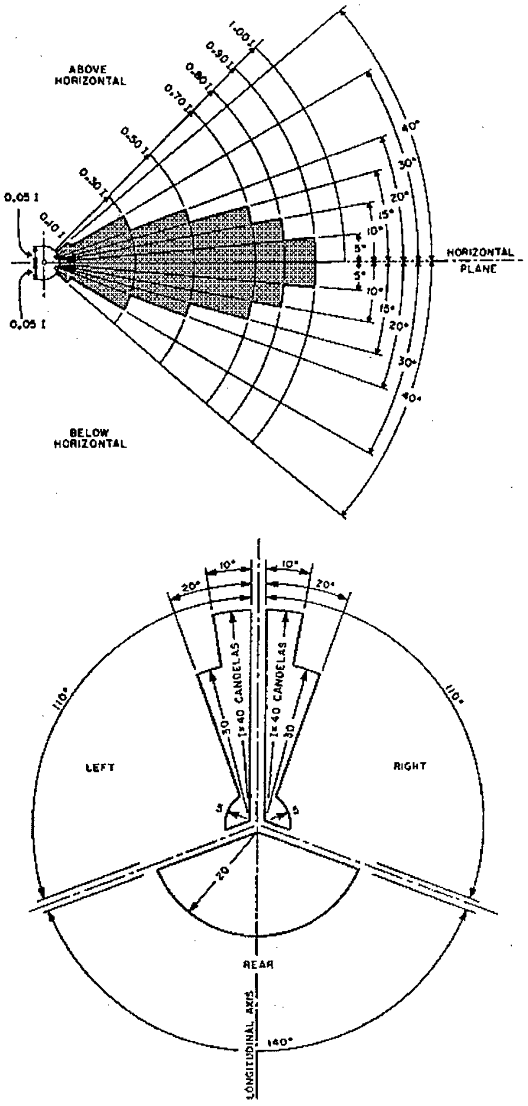

Figure 1. Position light minimum intensities in the vertical (top) and horizontal planes (bottom) [19].

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[5] Currently, the forward angles (approximately 60 degrees) of the red anticollision light are blocked to reduce interference to the NVGs.

The FARs define intensity requirements for individual light units measured from "dead ahead" within angular cones of 110 degrees horizontal by ±90 degrees vertical for the lateral position lights. Figure 1 depicts the minimum FAR intensity distribution requirements [19]. In the horizontal direction, the highest minimum intensities are required between 0 to ±20 degrees; beyond that, the intensity requirements drop off sharply. In the vertical direction, the highest minimum intensity is required at 0 degrees with respect to the horizontal plane of the aircraft centered at the lamp filament[6]. At positions above and below 0 degrees vertical, the intensity requirements drop off as multiples of the highest value. Based on the distribution of intensity requirements, the critical region for the lateral position lights can be defined as the cone between 0 to ±20 degrees in the horizontal and vertical angular directions.

Snook et al. [7] measured baseline intensity distribution profiles for position lights operating in bright and dim modes. Measured intensity profiles were compared to FAA requirements to determine the acceptability of dim mode operation and the impact of masking on light intensity distributions. They demonstrated that the luminance intensities of lateral position lights for the upper and lower horizontal angles were symmetrical. However, the horizontal and vertical angular intensity requirements are designed to optimize aircraft visibility in all directions within a 360-degree sphere. Thus, the 90-degree masking scheme does not meet intensity requirements for the area between the lights, since the lights are separated vertically by 4.8 feet. With these requirements as they are defined, it seems any masking of the position lights is unacceptable with respect to FAA regulations. Nevertheless, it may be possible to develop acceptable modified lighting for I^2 compatibility via the modification of the current definition.

Given the redundant intensity distribution within the 360-degree sphere around the aircraft, it stands to reason that the redundant (overlapping) light could be eliminated (masked) leaving a sphere of light around the aircraft within the FAR intensity requirements. Simple geometry and trigonometry give us the tools to calculate the appropriate angles for such masking. Ignoring penumbral effects, refraction of light due to edges, atmospheric bending etc., one can argue that the 90-degree masking scheme results in a "dark alley" between the upper and lower position lights since parallel lines do not converge (Figs. 2 and 3). However, light patterns from masking angles less than 90 degrees must converge. Using the following formula, the point of convergence was calculated for one rotor disk radius assuming FAA compliant illuminance values for the required angular distributions around the left side of the aircraft.

$$\tan\theta = \frac{r_c}{\frac{1}{2}d}$$

Where r_c = the radius of the rotor disk corrected for offset of the position light from the mast
d = the distance between the position lights

The radius of the rotor disk is 289.6 inches (24.1 ft; 7.36 m). This value corrected for position light offset is 235.6 inches (19.63 ft; 5.98m). The vertical distance between the two lights is 57.6 inches (4.8 ft; 1.46 m). The resulting value is 82.25 degrees, and rounding down for a more conservative 82-degree masking scheme (98 degrees unmasked) results in a lighting distribution pattern from the two lights that converges 7.6 inches (19.36 cm) inside the rotor disc. At this distance, a point source of light (luminance) from one of the two lights would be visible that meets any given angular intensity requirement (Figs. 2 and 3). Note that this requirement is satisfied only by allowing angular cone vertices to move from one light to the other as measurements transverse the equator of the sphere.

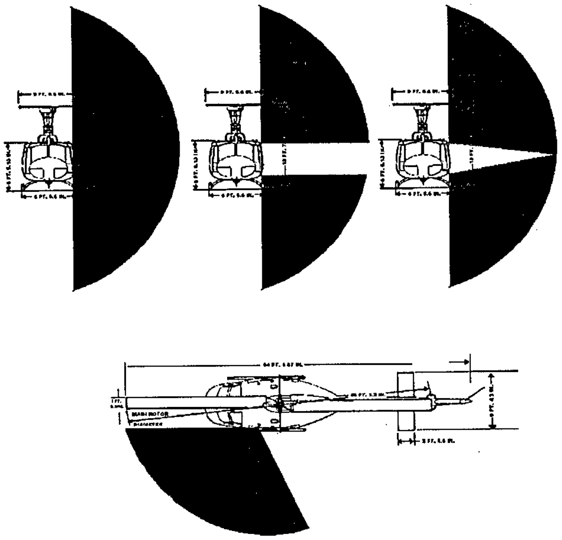

Figure 2. Side angular illuminance coverage for unmasked (left), 90-degree mask (center), and 82-degree mask (right). Horizontal coverage (bottom) does not change with masking pattern.

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[6] FAR requirements are stated in terms of *luminance*, the light intensity or luminous flux emitted from an infinitely small point source, where light flux is the rate or flow of visible energy. Intensity measurement of a light source generally is performed indirectly with instrumentation that measures *illuminance*. Illuminance is the density of luminous flux incident upon a surface. Intensity of a point light source can be calculated from illuminance using the inverse square law [7]:

$$\text{Illuminance (foot-candles)} = \frac{\text{intensity of source (candelas)}}{\text{distance (feet)}^2}$$

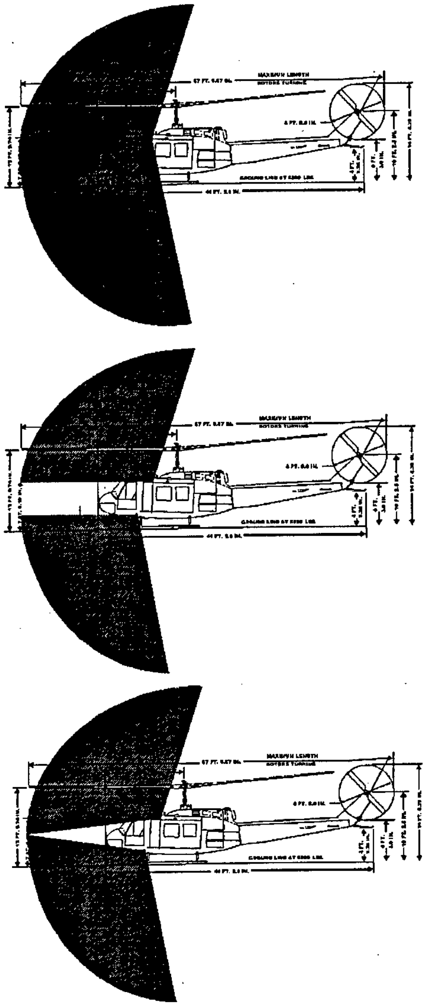

Figure 3. Forward angular illuminance coverage for unmasked (top), 90-degree mask (center), and 82-degree mask (bottom).

Video recordings were made using the single ANVIS tube and commercial camcorder described previously. These data show that NVD performance with the 82-degree masking scheme was equivalent to levels recorded under the old 90-degree masking scheme. Subsequently, USAAVNC requested that the U.S. Army Aviation and Troop Command (ATCOM) allow Fort Rucker UH-1s to be re-masked enabling data collection and validation of the 82-degree scheme. Data collected from USAAVNC's instructor pilot survey clearly indicate that the 82-degree masking scheme directly reduced NVD operational risks. Pilots reported that there were no problems with degradation or depth perception in NVD flight modes, and that the new masking scheme was just as effective as the old 90-degree masking scheme. Based on these data, the Army rescinded the earlier position light ASAM [10], and issued an ASAM directing the re-masking of both the red and green position lights according to the exact specifications of the 82-degree masking scheme [20].

CONCLUSIONS and RECOMMENDATIONS

The FAA establishes standards of exterior lighting to reduce the likelihood of aviation mishaps, to include mid-air collisions. Since 1978, the Army has been flying UH-1 aircraft exempt from current regulations under FAA waiver 3946D. This waiver expired on 31 December 1996. The goal of this project was to provide the Army aviation community with a standardized, permanent external light configuration that would satisfy unit training and mission needs for I^2 devices while maintaining adequate position light intensity distributions required by the FAA.

The FAA designed intensity distribution requirements to provide optimum visibility for aircraft operating in the NAS. Current requirements were developed for civil air-space operations prior to the introduction of I^2 devices into aviation. These standards were defined with the intention of maximizing unaided detection of aircraft in periods of reduced visibility and low illumination. Yet, in order for night missions to be performed safely and efficiently, aircraft position lighting must be compatible in both the civilian and military operating arenas. The integration of image intensifiers into Army aviation has greatly expanded mission capabilities. However, due to the operating characteristics of I^2 devices, the configuration for position lighting is not compatible with, and can have a negative impact on, the safety of mission execution. In attempts to alleviate the degradation of I^2 imagery by position light sources, the Army aviation community has modified lighting strategies to include operating with position lights in dim mode and operating with masked position lights in bright and dim modes under a FAA approved exemption. Modified exterior lighting or lights-out operations present an increased risk of possible mid-air collision with both civil and military aircraft[7].

This is not only a UH-1 problem: the OH-58 has the same problems as the UH-1; the UH-60 left lateral position light is too bright and creates excessive glare in aircraft crew compartment; and AH-1 crews report that the left lateral position light is too bright for formation flight and distracts the crew [7]. Consequently, many units address taping or painting of their position lights in unit standard operating procedures (SOPs) when conducting night aided formation flight. According to aviators surveyed, over 50 percent of Army aviation units were operating in the NAS with modified exterior lighting that did not comply with FARs.

The phenomenon that causes the decrease in NVD performance from the red position lights is due to activation of the ABC in the power supply of the NVD.

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[7] The U.S. Army Safety Center (USASC) notes that the risk of flying with unmasked lights exceeds the risk of colliding with other aircraft. There are no accidents in which position light masking was a contributing factor nor have there been any collisions or near-misses between Army aircraft with masked lights and civilian aircraft since the practice of masking was started 20 years ago.

Illumination from the red position lights floods into the cockpit and reflects off the ground around the aircraft, reducing the amplification of the goggles and reducing visibility of distant obstacles. The problem of light flooding into the cockpit/crew compartment from the lateral position lights is attributable in part to the location of the light units above and below the crew doors. One alternative for alleviating this problem would be to relocate the lateral position lights so that light emitted into the cockpit/crew compartment is reduced or eliminated. However, this may introduce new problems with FAA compliance depending on the eventual configuration and placement of the lights. Alternatively, the lighting industry is developing "NVD friendly" position lights using narrow bandwidth light emitting diodes (LEDs) with reduced near-infrared radiation. Both of these materiel solutions are relatively expensive as compared to the previously available options.

Of the previously available options (dim mode vs. masked), data show that the dim mode improved visibility more than masking. Dim mode is one of three selectable positions on Army helicopters (bright, dim, and off). Although intensities in the current dim mode fall below FAA requirements for flying in the NAS, incrementally dimmed steps between bright and dim modes are potentially feasible and offer a potential solution to the problem. Reportedly, Naval helicopters use a seven-step dimming switch where intensity at each dimming step is one-half that of the next higher step [6]. The primary exterior lighting specification for naval aircraft is MIL-L-006730C, which is based upon the same FAA intensity requirements as the Army specification MIL-L-6503H [16, 5]. Variable dimming on Army helicopters would allow flexibility for I^2 operations in restrictive environments.

Comparatively, masking is the most cost-effective solution. We calculated that the FAR could be satisfied at a distance of one rotor disk radius by an 82-degree masking scheme (leaving 98 degrees unmasked). Video recordings clearly document the objective effects of this masking scheme on NVD performance inside the cockpit (pilot's view), as well as the effects on other pilots outside the cockpit (i.e., multi-ship operations). Pilots' subjective observations indicate the new scheme significantly reduces NVD degradation as compared to operations with unmasked position lights. Additionally, there were no subjective conspicuity differences noted between the 90-degree and the 82-degree masking schemes. However, given the observation that fuselage and anticollision lights on the UH-1 cloaked the position lights, the issue of inter-aircraft I^2 degradation due to external lighting problems should be investigated further. Additionally, the global issue of lighting and masking problems on other aircraft deserves immediate attention.

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14. Abstract

These proceedings include the Technical Evaluation Report, Keynote Address, and 41 papers from the Symposium sponsored by the NATO/RTO Human Factors and Medicine Panel, which was held in San Diego, California, USA from 19-21 October 1998.

Rotary wing operations include military or civilian missions such as transport, medevac, and combat. A range of human factors problems may be implicated in helicopter mishaps, such as spatial disorientation or excessive workload. Furthermore, flying a helicopter can contribute to various specific pathologies, ranging from lower back pain to flight phobias. In several helicopter accidents, it has been suggested that injuries could have been avoided if adequate safety and protection technologies had been used. Although helicopters can be used for medevac involving large numbers of wounded, the use of helicopters has to be fully integrated with other transport systems and their equipment should be adapted for this type of mission. New training methods, such as crew resource management or spatial disorientation training, and new technologies, such as the "tactile situation awareness system" (TSAS) may, when fully implemented, help to avoid accidents. Utilization of swimming pools with specific tools for helicopter evacuation training can greatly reduce the risk of death by immersion. On the other hand, more effort is needed to improve the personal flight equipment. Although epidemiological data suggest that the risk of accidents and injuries is already low in certain air forces, the introduction of new protection technologies may help to further reduce the numbers of wounded. This symposium provided a review of the state-of-the-art concerning the various human factors implicated in helicopter operations, new methods and systems for increasing safety and efficiency of the helicopter operations, and new methods and systems for increasing safety and efficiency of the helicopter crew.

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