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Aviation Safety in the Rapid Onset, High-G Environment

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Interim Report for October 2001 to August 2005

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TECHNICAL REVIEW AND APPROVAL

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

FOR THE DIRECTOR

//signed//

MARK M. HOFFMAN
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14. ABSTRACT

This is a summary of research conducted on the high-G onset Air Force Research Laboratory centrifuge at Brooks City-Base TX. G-LOC and A-LOC research on the centrifuge is summarized. It was found that the G-LOC episode lasts longer than the nominal 24 sec previously described. It was found that pilot performance can be impaired up to 60 sec after a G-LOC. No adverse effect of sustained acceleration was observed in subjects who had PRK-treated eyes. There has been a proposal to eliminate the counter-pressure vest in pilots flying high-performance aircraft. Subjects reported no adverse effects of using Positive Pressure Breathing without the counter-pressure vest. The Navy's Smart Aircrew Integrated Life Support System (SAILSS) was evaluated on the centrifuge. The SAILSS is an advanced development project for the Navy with the objective of developing the next-generation aircrew life support system. The Human Information Processing under Dynamic Environment program was evaluated on both the Brooks and Wright-Patterson AFB centrifuges.

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Near Loss of Consciousness (N-LOC), Almost Loss of Counsciousness (A-LOC), G-induced Loss of Consciousness (G-LOC), COMBAT EDGE, go pills, PRK and G, pressure breathing, Libelle g-suit, TAILSS, SAILSS, Integrated Aircrew Ensemble, CRADA, HIPDE

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PREFACE

The research was conducted in the Aircrew Performance and Protection Branch (AFRL/HEPG), Biosciences and Protection Division, Human Effectiveness Directorate, Air Force Research Laboratory, Brooks City-Base, TX. The research was conducted under work unit 7757P804 "Aviation Safety in the Rapid Onset High-G Environment." Dr. Paul Werchan was the work unit manager. The period of performance was from 1 October 2001 to 31 August 2005.

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INTRODUCTION

Numerous studies and projects have been conducted on the Rapid Onset, High-G Environment Centrifuge at Brooks City-Base TX during the period of 1 Oct 2001 to 31 Aug 2005. This technical report summarizes those studies and describes the research including references in the literature.

AVIATION SAFETY IN THE RAPID ONSET, HIGH-G ENVIRONMENT

Acceleration-Induced Near Loss of Consciousness (NLOC)

Electroencephalography (EEG), Electrooculography (EOG), and Electrocardiogram (ECG) recordings, blood pressure recordings, ear oximeter tests for oxygen saturation, a flight simulation tracking task and a verbal digitized calculation test for performance were all used and measured in different G-exposures in the human centrifuge. Data collection for phase one, which included the testing of suitable G-profiles for eliciting Near Loss of Consciousness (N-LOC) in the centrifuge, was completed. Results include seven G-profile exposures in a total of 58 different G-exposures with 5 subjects on 10 separate days. After careful review of the video recordings of these 58 tests, 15 borderline N-LOCs, 22 N-LOCs, and 3 G-induced losses of consciousness (G-LOCs) were found, while in 18 tests no apparent adverse physiological or behavioral events were found. This was an intentional N-LOC study directed at establishing a better understanding of the N-LOC phenomenon. (6)

Tailored Breathing and Anti-G Suit Pressures in Relation to Anthropometric Data and Pressurized Arm Sleeves and Gloves for G-Protection

The purpose of this research was to study whether or not individuals of different body sizes can benefit from pressure breathing during G and G-suit inflation schedules tailored to their personal anthropometry. The effects of pressurized arm sleeves and gloves on acceleration tolerance were also tested. The premise is that tall persons with a long blood column from eye level to heart and from heart to feet will have a lower G-tolerance

compared to short persons with shorter blood columns. This study assessed the possible protective advantage conferred by individually calculating breathing and anti-G suit inflation pressures for individuals of different sizes using their eye-to-heart and thigh-to-heart distance, respectively. The addition of pressurized sleeves and gloves, earlier developed and shown to substantially decrease G-induced arm pain, was also evaluated for possible G-protection. The sleeves and gloves were inflated on a schedule calculated to support a hydrostatic column from the middle of the arm to the heart. Three different conditions were tested in the centrifuge including a control with COMBAT EDGE and ATAGS standard pressures, tailored COMBAT EDGE and ATAGS pressure schedules, and tailored COMBAT EDGE and ATAGS pressure schedules combined with the addition of pressurized arm sleeves and gloves. The G-exposures were gradual and rapid onset runs, and simulated aerial combat maneuver runs up to +9 Gz.

G-MED

This study began in June 2002 and it looked at the effort of "Go Pill" stimulant pharmacological agents administered to trained subjects after a minimum period of 17 hours of sustained wakefulness. Testing was performed during the circadian nadir (0200-0500 local time). +Gz tolerance, endurance, and a variety of aviation performance parameters were measured during this period. Subject performance was compared against placebo and rested daytime performance. The drugs compared were dextroamphetamine 10 mg, modafinil 200 mg, pemoline 37.5 mg, and methylphenidate 10 mg. Side effects and impact on recovery sleep were surveyed. A secondary purpose of this study was to develop a simulator-based aviation performance assessment tool to compare performance impact and side effects of potential operational and therapeutic drugs considered for use in aviators. Performance measures from the Performance Assessment (Standardized) Simulation System (FPASS) were compared against the Automated Neuropsychiatric Assessment Metrics (ANAM). This was designed to determine whether the simpler and more aviation-relevant FPASS testing tool could match the validated ANAM battery of tests for measuring and comparing the impact of circadian desynchronosis and pharmacological agents on aviation performance. The impact of sustained wakefulness and circadian nadir on +Gz tolerance and endurance were the principal issues addressed in this study. The results were presented at the 2003

Aerospace Medical Association meeting (4).

Effects of Acceleration on Corneal Stability in Postrefractive Keratectomy (PRK) Subjects

This research investigated the effect of acceleration on the surface characteristics of the cornea of subjects who have had excimer photorefractive keratectomy (PRK) performed for myopia. This study was in direct support of an ongoing study at the Ophthalmology Branch at Brooks City-Base to investigate the clinical course and duty impact of PRK on myopic active-duty USAF personnel. Volunteer subjects (male and female) were selected who met both the criteria for inclusion into the PRK study as well as medical qualifications to be centrifuge subjects. Subjects were trained in the Brooks City-Base centrifuge to a goal of 15-sec plateaus of +3, +5, +7, +8, and +9Gz during a simulated aerial combat maneuver (SACM). Subjects were then separated into two different groups based on training performance. The +5 to +9 SACM group was provided with pressure breathing during G (COMBAT EDGE). On average, each subject's participation spanned approximately 27 months, including a 4 - to 6-week period of preliminary centrifuge training and 6-, 12-, and 24-month follow-up centrifuge assessments of the effects of acceleration on the post-PRK cornea. A standard battery of visual performance tests (VPT, visual acuity and refraction) and corneal measurements (topography and keratometry) were performed on all subjects before and after centrifuge exposures. Also, visual acuity was tested during high-Gz peak sustained centrifuge runs. Due to the extreme attrition rate of subjects, baseline data were collected on 19 subjects, 6-month post on 13 subjects, 12-month post on 12 subjects, and only 2 subjects returned for the 24-month post follow-up. Data analysis indicates no adverse effects of +Gz on PRK treated eyes.

Joint Service Aircrew Mask (JSAM) Centrifuge Evaluation

The objective of the Joint Service Aircrew Mask (JSAM) program is to develop a respirator for individual aircrew that provides "above the shoulders" head, eyes, respiratory and percutaneous protection against chemical and biological (CB) warfare agents, radiological particles, and toxic industrial materials (TIMs) as well as continuous

protection against CB agent permeation. Additionally, when integrated with aircraft-mounted and crew-mounted breathing equipment (in aircraft so equipped), the JSAM will provide pressure breathing for G (PBG) protection during air combat maneuvering flight. Ideally, selected system components will be usable as an aircrew's everyday oxygen mask (in aircraft so equipped) for flying in peacetime or wartime environments. AFRL/HEP and NAVAIR were tasked to test the JSAM system performance during the Program Definition and Risk Reduction (PDRR) acquisition phase of the JSAM program. During PDRR, two contractors provided the Government with tactical JSAM variants for centrifuge testing. This testing was designed to determine both the mechanical performance of the mask under +Gz stress and its ability to provide sufficient airflow to enable comparable +Gz tolerance to the current COMBAT EDGE system.

+Gz Acceleration Induced Loss of Consciousness (GLOC) and the Effect of Sensory Stimulation on Reducing Recovery Time

This is the last of four protocols designed to identify novel ways to shorten the recovery time following deliberate GLOC of subjects in a centrifuge. This protocol focuses on the presentation of a stimulus (sound, light, or vibration) immediately following GLOC (absolute incapacitation period) on four separate days (includes one non-stimulus "control" day). The subjects were trained to extinguish the stimuli as soon as they regained consciousness, and to regain control of a combination math/tracking task that was initiated prior to the GLOC exposure. (5)

Pressure Breathing During G without a Counter-Pressure Vest

This study was conducted to determine whether safe and adequate G-protection could be maintained if the COMBAT EDGE counter-pressure vest were eliminated. Operational aircrew have indicated the pressure vest is hot as it adds another layer of apparel to the pilot. Eleven subjects, including five F-15 aircrew, completed 6G per second onset centrifuge exposures up to +9 Gz using unassisted pressure breathing for G (PBG) at 60 mm Hg pressure with and without the counter-pressure vest. Additional G-exposures using pressures of 0, 30, and 45 mm Hg were performed without the vest. Elimination of the COMBAT EDGE counter-pressure vest did not significantly reduce G-tolerance. The

use of PBG, with or without the vest, was preferred by all test subjects. PBG at 60 mm Hg produced the highest G-protection and was preferred by the test subjects over lesser pressures. Subjects reported no adverse effects from use of PBG without chest counter-pressure. Whether PBG without counter-pressure will increase fatigue during multiple sorties was not determined. (3)

Impact of Selective and Non-Selective Alpha Blockade Agents on +Gz Tolerance

Active-duty urologists have been faced with an increasing dilemma of treating our aviators with bladder outlet obstructive symptoms. The USAF currently restricts the use of both finasteride (Proscar®) and alpha blocking medications for treatment of benign prostatic hypertrophy (BPH). The purpose of this study was to determine the impact on +Gz tolerance/endurance of tamsulosin (Flomax®) and terazosin (Hytrin®), respective selective and non-selective alpha-adrenergic blocking agents, versus the absence of these medications. Preliminary results were presented at the Aerospace Medical Association (ASMA) 2003 annual meeting. (2)

Plotting the Recovery Pattern of Saccule Function in Healthy Subjects Soon after High +Gz Exposure

The purpose of this investigation was to determine the effects of high +Gz on the function of the vestibular system. More specifically, this research effort was aimed at establishing the normal adaptability, fatigue and recovery process of saccule function due to acceleration-related stresses on the otoliths in pilots and aircrew. A quantification of the normal recovery process will assist in establishing a metric for clinical use when one must make a determination to return a pilot or aircrew member to flight duty after reported episodes of dizziness.

Effects of Simulated Spaceflight on Virus-Specific Immunity

The principal objective of this project was to use hypergravity and bedrest to effectively simulate certain aspects of spaceflight in order to better understand how acute changes in gravitational force affect the human immune system. Previous studies of astronauts by project collaborators have found elevated levels of cortisol after launch and during

spaceflight, events involving acute acceleration and microgravity. In addition, significant increases in stress hormones (i.e., cortisol, catecholamines) were found after landing. Those studies found increased shedding of Epstein-Barr virus (EBV) and cytomegalovirus (CMV), two medically important herpes viruses, during spaceflight, along with evidence of decreased cellular immunity. These increases in stress hormones directly correlated with CMV and EBV reactivation. Thus, latent herpes virus reactivation in these astronauts may have resulted from both direct (i.e., stress hormones) and indirect (i.e., decreased immune function) mechanisms stemming from launch and landing acceleration. A ground-based model has been developed (head-down bedrest combined with centrifuge exposures) that simulates the multiple gravitational changes that occur during spaceflight (hypergravity at launch, microgravity during flight, hypergravity at landing). This model system tested the hypothesis that the combined effects of hypergravity and bedrest along with associated physical and psychological stress will decrease virus-specific cellular immunity and reactivate latent herpes viruses.

Tactical Aircrew Integrated Life Support System (TAILSS) Centrifuge Evaluation

The primary goal of the study was to assess the ability of the Aircrew Integrated Life Support System (AILSS) to obtain clear, reliable ECG, EEG, electromyography (EMG), near infrared spectrography, temperature, humidity, mask pressure, and anti-G suit pressure values during exposure to high +Gz. In addition, the ability of the AILSS State Risk Predictor program (SRP) to control anti-G suit pressure and pressure breathing for G (PBG) for US Navy COMBAT EDGE (NCE) and TAILSS (Tactical AILSS) ensembles was assessed. The SRP operated the anti-G equipment under two modes: standard US Navy COMBAT EDGE and with biofeedback. The ability of the SRP to detect characteristic physiologic changes associated with "almost loss of consciousness" (ALOC) was also assessed. This portion of the study was a follow-up to the NLOC Phase I protocol conducted at Brooks in 2002.

Evaluation of the Suitability of the CSU-13B/P G-suit for Use in the F/A-22

The Commander of Air Combat Command requested that the CSU-13B/P G-suit be evaluated as a replacement for the Advanced Technology Anti-G Suit (ATAGS)

currently worn by F/A-22 pilots. AFRL/HEPG completed necessary modifications to 25 CSU-13B/P suits (move the suit's inlet hose from the left to the right-hand side and change the hose connector) and evaluated performance when used with the F/A-22 Breathing Regulator Anti-G Valve. HEPG also evaluated performance of the CSU-13B/P when used with an extended inlet hose routed across the ejection seat. That hose routing might allow for use of the CSU-13B/P in its standard configuration (suit inlet hose on the left-hand side). No statistical differences in G-levels were found during relaxed Gradual Onset Rate (0.1 G/Sec) (GOR) and straining GOR between the different anti-G suit conditions I-III. With condition III (COMBAT EDGE and ATAGS) discomfort level was significantly lower than with condition I (MOD), and heart rate was lower than with I (MOD) and II (STD). No statistical differences were found in discomfort rating between the different anti-G suit conditions I-III, but duration at G was longer and heart rate was lower under condition III than under conditions I and II. The truncated durations (90s max), discomfort or heart rate were not statistically different among the three conditions, but, for effort, condition III yielded lower scores. (2)

Brooks City-Base Centrifuge Refurbishment

A three-week refurbishing project was completed on the Brooks City-Base Centrifuge (Figures 1 and 2). This included a fresh coat of paint with a modern color scheme for the centrifuge, centrifuge room, control room and adjoining room. In addition to painting, the video and computer monitors in the console were replaced with 19-inch rack-mount LCD displays. The X-Y plotter and subject data tracking computer functions were merged into a single computer for displaying centrifuge acceleration profiles and tracking subject data on a single LCD display. Three 32-inch LCD monitors were added to the control room and two cameras were added to the centrifuge pit to improve situational awareness and safety of centrifuge operations. The upgrades have not only given the centrifuge a cleaner, sleeker appearance, they have helped to improve operational flexibility and efficiency.

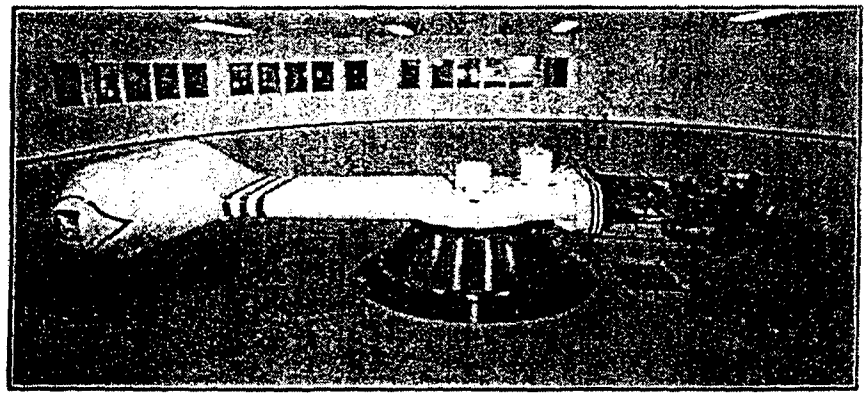

Figure 1. Air Force Research Laboratory Centrifuge

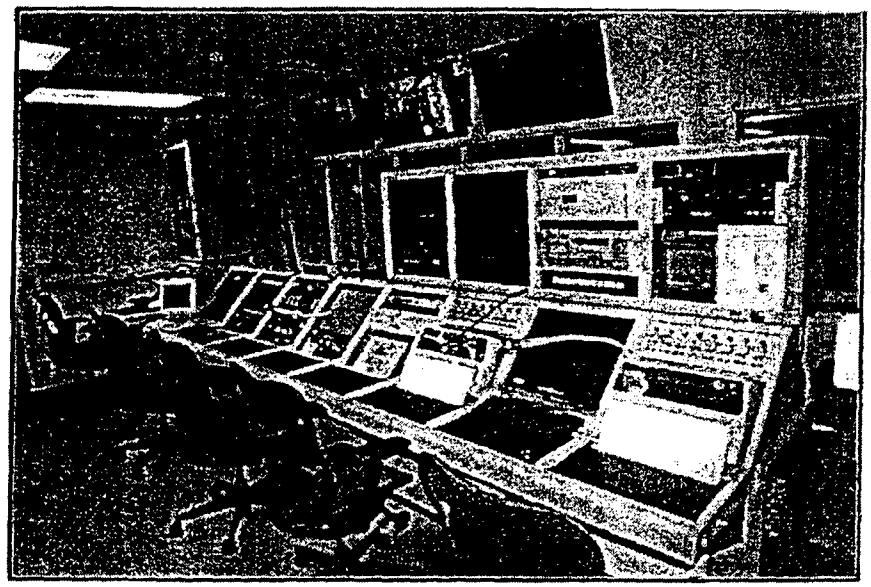

Figure 2. Centrifuge Control Room

Cooperative Research and Development Agreement (CRADA) between BSI Aerospace Systems Inc. and AFRL/HEP

The purpose of this CRADA is to collect data that define the performance of an advanced G-compensating regulator and a non-linear pressure output G-valve designed and built by BSI Aerospace Systems Inc. The goal of the advanced regulator and G-valve development is to increase breathing comfort for aircrew during high-G exposure, extend aircrew tolerance to high-G, and improve communication during use of positive pressure breathing for G. AFRL/HEP conducted unmanned and manned centrifuge tests of the regulator and G-valve as part of the performance evaluation process. To date, unmanned

tests of the G-valve and breathing regulator have been conducted, and the results show the need for further refinement of both items.

Libelle (SAGE) G-suit Tested

Air Combat Command requested testing of the Libelle G-suit in 2003 subsequent to Foreign Comparative Testing of the suit in F-15s and F-16s at Eglin AFB. ACC had mixed results with the Libelle and had several research questions for AFRL to investigate via centrifuge studies. Both HEPG centrifuge facilities were used to evaluate the suit from January to April 2004. AFRL/HEPG received the Libelle G-suits in January 2004 and immediately began testing the suits. G-naïve subjects were selected to participate in the study in order to eliminate the possibility that subjects would revert to a learned L-1 straining maneuver. The results were forwarded to Air Combat Command. (5)

HIPDE Program Underway at Both Centrifuges

The Human Information Processing in Dynamic Environments (HIPDE) program's Phase II SBIR "Human Performance Model for High G" with NTI was completed. Deliverables from the SBIR include a battery of twelve tasks designed to test cognitive ability at G (G-PASS), as well as a predictive model of cognitive ability at G (G-TOP). G-TOP will be validated using G-PASS tasks at the Dynamic Environment Simulator facilities at Wright-Patterson Air Force Base and the centrifuge at Brooks City-Base. Five of the twelve tasks have been completed and the preliminary results suggest significant decreases across the various cognitive and motor tasks. The ultimate goal of the HIPDE program is to transform AFRL sustained acceleration research into a modeling and simulation analysis tool-set useful for wargaming, training, and simulation-enhanced acquisition. In order to accomplish this, the cognitive model will be incorporated into one or more constructed pilot models. AFRL/HEPG is working with the Simulation and Analysis Facility (SIMAF) to incorporate the model into the Man-in-the-Loop Air –to-Air System Performance Evaluation Model (MILAASPEM). A light loss model, currently being developed in-house as part of the HIPDE program, will be the first stage of this process. Discussions to promote the HIPDE models in other constructed pilot programs are currently underway.

CONCLUSION

G-LOC and A-LOC research on the centrifuge was performed. It was found that the G-LOC episode lasts longer than the nominal 24 seconds previously described. It was found that pilot performance can be impaired up to 60 seconds after a G-LOC. No adverse effect of sustained acceleration was observed in subjects who had PRK-treated eyes. There has been a proposal to eliminate the counter-pressure vest in pilots flying high performance aircraft. Subjects reported no adverse effects of using Positive Pressure Breathing without the counter-pressure vest. The Navy's Smart Aircrew Integrated Life Support System (SAILSS) was evaluated on the centrifuge. The SAILSS is an advanced development project for the Navy with the objective of developing the next generation aircrew life support system. The Human Information Processing Under Dynamic Environments program was evaluated on both the Brooks and Wright-Patterson AFB centrifuges.

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