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AIR FORCE HUMAN RESOURCES LABORATORY

MOTION AND FORCE CUEING REQUIREMENTS AND TECHNIQUES FOR ADVANCED TACTICAL AIRCRAFT SIMULATION

By

William B. Albery
Don R. Gum

ADVANCED SYSTEMS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

Gerald J. Kron
Singer – Link Co.
Binghamton, New York 13901

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AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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The Air Force Human Resources Laboratory (AFHRL) has the responsibility for research and development of advanced simulation techniques, including motion and force cueing requirements and techniques. This report is a summary of the efforts currently underway at AFHRL under Projects 6114 and 1958 which are directed at advanced tactical aircraft simulation. The approach being pursued is two-fold; the first part includes efforts directed towards building a data base for use in developing cueing requirements; the second part includes efforts to improve the performance of existing devices that have been shown to be somewhat effective and to develop new devices and techniques as indicated by the data base efforts. Exploratory efforts including the development of a composite sensory model, the design of high-g augmentation devices, the development of a myoelectric feedback display

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dimming technique and the collection of g-cue environment data are discussed. An advanced development effort, the advanced g-cueing system (including g-seat, g-suit, and seat shaker), is highlighted.

SUMMARY

The approach being pursued by the Air Force to advance motion and force cueing technology for tactical air flight simulators is twofold. The first part includes efforts directed towards building a data base for determining motion and force cueing requirements. The second part includes efforts to improve the performance of existing devices that have been shown to be somewhat effective and to develop new devices and techniques as indicated by the data base efforts. The data base development involves looking at the pilot who receives motion and force cues and the aircraft and environment which impart the motion and force cues. Models of human motion and force sensory mechanisms (vestibular, tactile, visual, and non-vestibular proprioceptive) describing how motion is perceived have been developed, and the motion and force environment for tactical aircraft performing various maneuvers is being characterized. The results of these efforts are being used to define motion and force cueing requirements and concepts for new devices to impart the necessary cues. Cueing device development efforts include the development of the next generation g-cueing (g-seat, g-suit, and buffet) system with improved response and onset cueing capability; techniques for myoelectric control of visual simulation system brightness and field-of-view as a function of the g-force environment and pilot physical action; and designs for systems such as arm, thigh, and head loading devices to provide for simulation of the extremely high-g flight environment.

PREFACE

This report consists of a technical paper of the same title presented at the Advisory Group for Aerospace Research and Development (AGARD) Flight Mechanics Panel Specialists meeting on Piloted Aircraft Environment Simulation Techniques. The meeting was held in The Royal Library (Albertina), Mont des Arts, Brussels, Belgium, 24–27 April 1978. Mr. Don R. Gum, AFHRL/ASM, gave the presentation. When this paper is printed by AGARD in June 1978, the AGARD proceedings of the specialists meeting can be obtained from NTIS, 5285 Port Royal Road, Springfield, Virginia 22151.

The major portion of section II of this report, Motion and Force Cueing Device Development and Refinement, comes from a technical paper by Gerald J. K.on (with Young, Albery) entitled "High-g Simulation – The Tactical Aircraft Simulator Problem." The paper was presented at the 10th NTEC/Industry Conference, Orlando, Florida, 15–17 November 1977 and is published in NAVTRAEQUIPCENT IH-294.

In this report, the following symbology is used:

g	= denotes sustained acceleration $1g \cong 9.8$ m/sec^2
ms	= millisecond
Hz	= cycle per second (Hertz)
ASPT	= Advanced Simulator for Pilot Training
SAAC	= Simulator for Air-to-Air Combat
ALCOGS	= Advanced Low-Cost g-Cueing System
F-4E18	= F-4E simulator, number 18
STARS	= Simulation and Training Advanced Research System

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I. DATA BASE DEVELOPMENT

In the motion and force simulation area, like most all other technology areas, a fundamental knowledge base is required to permit intelligent decisions concerning the need or requirement for and the design of various cueing devices and techniques. Our current data base is inadequate in terms of knowing precisely what kind of motion cueing is required for various flying training tasks. Although our knowledge base, necessary for designing a device once a requirement has been established, has improved considerably over the past few years, additional data are required in several areas. Several efforts are underway to help fill these knowledge gaps by better describing the motion and force environment and better understanding of how a pilot senses and utilizes motion and force information.

Motion Sensory Mechanism Modeling

In order to obtain a better understanding of how a pilot senses and utilizes motion and force information in flight, an effort was initiated in early 1976 to investigate and to develop and/or refine models of the more prominent motion sensory mechanism. This work stimulated and sponsored by the Air Force Human Resources Laboratory (AFHRL) is being performed under the direction of Dr. Laurence Young of the Massachusetts Institute of Technology. This effort has resulted in the development of a unified, or composite, model for motion and orientation perception which integrates four sensory modalities including: vestibular, visual, nonvestibular proprioceptive, and tactile (Figure 1). The individual models are in various states of refinement and validation, with the vestibular model (semicircular canals and otolith) being the most understood and refined, the visual model next most developed, and the tactile and proprioceptive models being initial first-cut models. Although there are still gaps in our knowledge of the various sensory modes and considerable experimental data collection and model validation remain to be done, it was felt that there was currently enough information available to put together a first-attempt unified perception model (Borah, Young, & Curry, 1977).

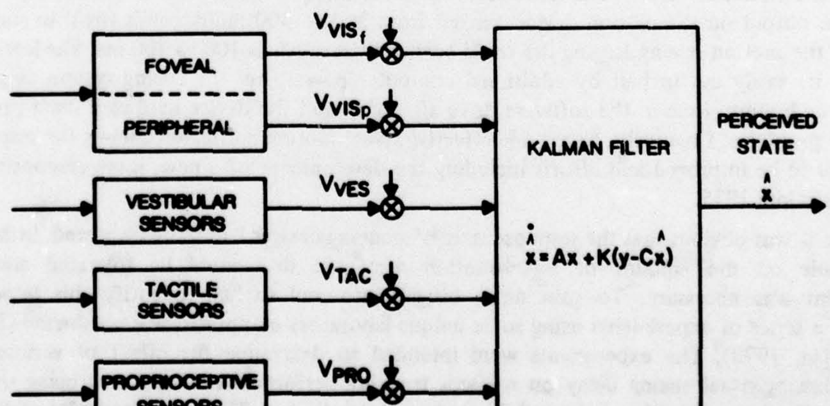

Figure 1. **Composite sensory model. The unified model for motion and orientation perception integrates the four sensory modalities at the left via a Kalman filter.**

The individual component models are largely physiologically based, and in order to produce a composite perception model, the physiological had to be related to the psychological. The biological control processor, which integrates information from the various sensors, is considered to function in a manner similar to an optimal estimator. A natural choice for the psychophysical function part of the model was a Kalman blending filter.

The model development effort, in addition to producing a first-attempt unified model, has identified a number of deficiencies in the motion and force psychophysical data. The Man-Carrying Rotational Device (MCRD) developed by the National Aeronautics and Space Administration (NASA) at their Ames Research Center is currently being used to gather data on the threshold of rotational motion. The advanced g-cueing system described later in the paper, as well as an in-flight simulator, will be used to obtain additional human tactile and pressure receptor data. Also, experiments have been designed to provide data on the relation and interaction of visually and proprioceptively induced motion using a wide field-of-view visual system in concert with a platform motion system.

Motion and Force Environment Characterization

Another important part of the effort to develop an adequate data base has been to obtain data on the motion and force environment to which the pilot is subjected and data on the aircraft/pilot interaction. Efforts are underway to obtain motion and force characterization data at the pilot station on fighter/attack aircraft for various flight maneuvers using ground-based engineering simulations. In addition, data are to be collected on aircraft/pilot interaction, such as body contact pressure and loading and body movement within the cockpit, through the use of an instrumented inflight simulator. Special pressure – sensitive seat overlays will be developed, and cameras are to be installed to record the aircraft/pilot interaction. Various maneuvers will be flown in the aircraft while these data, as well as data on the subject's perceived orientation, are being recorded.

Visual/Motion Time Delay Experiments

Visual/motion cue correlation problems have been encountered in the development of advanced Air Force training simulators for the T-37B and F-4E aircraft (Gum & Albery, 1977). These problems have been traced to excessive time delays inherent in motion and force cueing devices, such as the first generation six-degrees-of-freedom synergistic platform motion system and the first generation pneumatic g-seat. Approximately 10% to 50% of the total cue correlation problem was also attributable to low computational iteration rates. Total simulator delays, as measured from initial control input to observed acceleration output on the motion device, ranged from 200 to 400 milliseconds (ms). In some cases, this resulted in the motion cueing lagging the visual cueing by as much as 100 to 200 ms. The low iteration rate delays can be easily cut in half by additional computer power, but the cueing system delays caused by excessive cue buildup time in the software drive algorithm and the device hardware itself presented more formidable problems. Obviously, to provide effective visual/motion correlated cueing, the response of these systems had to be improved and efforts including the development of a new, more responsive g-seat were undertaken in late 1975.

While it was obvious that the response time of g-cueing devices had to be improved, little information was available on the amount of visual/motion mismatch that could be tolerated and how much improvement was necessary. To gain more insight into and to help quantify this important design parameter, a series of experiments using some unique laboratory equipment was conducted (Fiore, Junker, & Cotterman, 1978). The experiments were intended to determine the effect of various amounts of motion-following-visual cueing delay on roll-axis tracking performance. The device being used is a single axis roll motion system with a narrow field-of-view visual display. The plant dynamics of the system are similar to the roll dynamics of a high performance fighter aircraft. The motion/visual asynchronization range used in the experiments was from zero to 300 ms with delay conditions of zero, 80 ms, 200 ms and 300 ms. Also a static or no-motion condition was used. A delay of approximately 200 ms produced tracking performance equivalent to the no-motion condition. A delay beyond 200 ms produced performance significantly degraded over the no-motion conditions. Best performance occurred as expected with zero delay. From these data it appears that the motion-following-visual cueing tolerance should be no greater than 200 ms and probably much less.

Applications of Technology Base Data

The unified motion and force sensory model is being used to give researchers insight into which sensory mechanisms are being stimulated and to what degree under various flight conditions. The results of this effort are being applied to the development of new motion cueing hardware and drive techniques, such as the advanced g-seat described later in this report. Figure 2 shows the sensory model in a flight condition being stimulated by simulated aircraft forces and moments at the top of the diagram and stimulated by forces and moments from a simulation through various cueing devices at the bottom of the diagram. The use of the model as shown in this example permits a comparison of the perceived motions and forces as created by an aircraft simulation directly and by various cueing hardware and drive concepts driven by a simulation. Through such a process involving selective experimentation with existing or proposed simulator hardware/software, an optimum match of perceived orientation in the aircraft and simulator can be achieved.

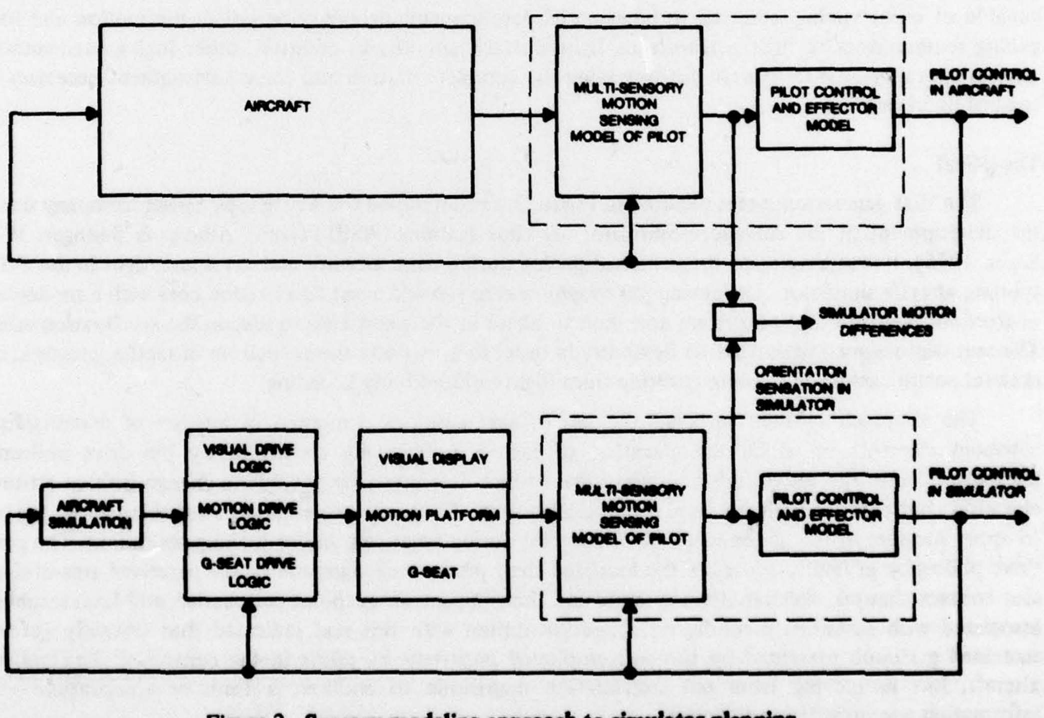

Figure 2. **Sensory modeling approach to simulator planning.**
Differences of pilot perception in the actual aircraft (at top) and in a simulator (bottom) can be examined more realistically provided a human sensory model exists (dashed box). Such a model permits a comparison of the perceived motions and forces as created by an aircraft simulation directly and by various cueing harware and drive concepts driven by a simulation.

Just because certain motions and forces are present and perceived in flight does not necessarily mean that they are important in performing or learning certain flying tasks. The motion and force characterization effort in addition to providing information for cueing system design is essential for performing task analyses to identify cueing requirements. The motion and force profiles that are being generated for various aircraft on a maneuver-by-maneuver basis are to be used as an aid in performing task analyses. These data profiles will allow the analysis to be conducted on a more objective basis, helping the pilot/analyst reconstruct or recollect the cue environment.

II. MOTION AND FORCE CUEING DEVICE DEVELOPMENT AND REFINEMENT

The first generation six-degrees-of-freedom synergistic platform motion systems were used with transport aircraft simulators in their first training simulator field application. Their low response characteristics when coupled with the dynamics of these transport aircraft simulators did not create a significant cue correlation problem. The first generation g-seat was designed for the fighter and trainer type of simulator, but primarily as a sustained cueing device. Its response delays were similar to those of the synergistic motion system (Gum & Albery). It was felt, however, from the early sensory mechanism modeling work, that the g-seat could be an effective onset cueing device. Since the g-seat interfaces with the most responsive sensory mechanisms, the tactile and pressure receptors, it can be argued that it should be the most responsive of the g-cueing devices. Improved platform motion systems and an improved g-seat capable of onset cueing were felt to be essential developments necessary to satisfy the motion and force cueing requirements of high performance fighter/attack aircraft. In addition, other high-g augmentation devices appeared to offer benefit for providing the complete motion and force environment necessary for tactical flight training.

The g-Seat

The first generation g-seat pictured in Figure 3 was developed for AFHRL by Singer Company during the development of the Advanced Simulator for Pilot Training (ASPT) (Gum, Albery, & Basinger, 1975; Kron, 1975). It was developed for sustained cueing during basic airwork and aerobatic flight in the T-37B training aircraft simulator. The cueing philosophy was to provide onset acceleration cues with a six-degrees-of-freedom platform motion system and then to blend in the g-seat cues to sustain the acceleration effect. The seat was designed with research flexibility in order to investigate the simulation of tactile, pressure, and skeletal posture associated cueing resulting from flight-induced body g-loading.

The approach selected involved the use of seat cushions composed of mosaics of pneumatically activated elements in which the elevation of each is individually controlled by the drive philosphy programmed into the simulator's computational system. It is therefore possible to change cushion attitude, elevation, and contour with the same mechanical system. The g-seat also employs a variable-tension lap belt to apply pressure in the abdominal area of the pilot during negative g and/or braking conditions. The g-seat drive philosphy primarily addresses the localized flesh pressure changes and tactile perceived area-of-flesh/seat contact changes, skeletal attitude shifts and their impact on eyepoint perspective, and flesh scrubbing associated with sustained g conditions. Experimentation with this seat indicated that not only were the sustained g stimuli presented by the seat employed positively by pilots in the control of the simulated aircraft, but in moving from one acceleration magnitude to another, a form of acceleration onset information was provided to the pilot.

The g-Suit

The g-suit cue represents an excellent example of apparent pilot g-level assessment by way of association. The g-suit is employed in tactical aircraft to counter blood pooling in the lower extremities during high-g conditions. A predominant early perception experienced by the pilot, well before any blood

Figure 3. **First generation g-seat.**

Developed for AFHRL by the Singer Co. – Link Division in 1971, this pneumatic g-seat which employs 16 movable plates (bellows actuated) in the seat pan and 9 in the back rest has been installed in U.S. Air Force and Navy and Swedish Air Force simulators.

restricting effects materialize, is a tactile perception associated with the pressure induced by the g-suit. The pilot appears to associate this perception with increased g-loading. Providing a similar experience within the simulation by inflating operationally issued g-suits according to the simulated flight g-loading produces a very strong g-loading cue for pilot utilization. Equally important is the fact that this cue is made available by a device which is present in the actual task; therefore, visual environmental fidelity is maintained within the simulation.

Limitations and Ranges of g-Cueing Devices

The successful introduction of the g-seat within the training and tactical aircraft simulation environment was an extremely significant milestone in terms of mid-range g-level cueing. However, just as the motion system has its limitations, so does the g-seat. As previously mentioned, the g-seat confines its physiological stimuli production to the pilot/seat inertial coupling areas. It makes no demands on the pilot other than to sit in the seat and buckle the strapping that is used in the seat, as well as in the actual aircraft, thereby maintaining visual environmental fidelity. As a consequence of this approach, pressure buildup in

the back/buttocks area is limited to that obtainable from the 1g weight of the subject, as modulated by variation in the shape of the flesh-supporting surface. Neck muscular stimuli associated with g-loading of the helmet and head are limited to those available by changing the attitude of the torso so that the 1g gravitational weight of the helmet/head loading varies neck load. Displacement of body extremities through interplay of the skeletal structure and cushion surface attitude is limited to that range of attitudinal change which is compatible with the tactile and pressure cueing being delivered. Inertial load buildup in the arms and visceral effects and their perceivable by-products cannot be provided.

A limitation identified with the first generation g-seat is its low bandwidth (less than 1 Hz). Because of this low bandwidth, it is impossible for the pneumatic g-seat to pass high frequency acceleration cues, such as buffet. Furthermore, in the absence of a platform motion system whose principal purpose is to track and reproduce the leading edge of an acceleration profile, it is almost impossible for a low bandwidth pneumatic g-seat to present onset acceleration cues in a tactical aircraft simulator. This limitation was recognized soon after the development of the g-seat for the ASPT.

Two studies were initiated in 1975. The objective of the first study was to improve the g-seat pneumatic control system by investigating a closed-loop air bellows/servovalve arrangement. The bandwidth employing feedback techniques was extended to approximately 3 Hz, but displays enough overshoot to warrant continued control system investigations. The objective of the second study was to investigate a simpler, low cost g-seat configuration. Using dual-celled air bladders for the seat pan and a single-celled bladder for the backrest, a much simpler g-seat was simulated on the ASPT g-seat. This emulation on the ASPT was quite effective and resulted in the recommendation for a different approach to g-seat geometry for future seats.

Advanced g-Cueing System Development

Because of the response limitation of the first generation seat and also of the g-suit and seat shaker devices, in 1976 AFHRL contracted with the Link Division of the Singer Company for the development of an advanced g-cueing system. The objective was to develop a simpler, more responsive g-cueing system for the tactical aircraft simulators.

Since the first generation g-seat was designed to provide only a sensation of sustained acceleration, it employs a cueing philosophy which does not make use of transient onset cueing. This philosophy has been well received for sustained cueing and, somewhat unexpectedly, it was found that a measure of onset cueing is delivered as a by-product of the sustained cueing philosophy. Nevertheless, ongoing work in sensory systems modeling indicates that improved tactile and pressure cueing should be attainable through more sophisticated transient cueing drive schemes. To support the development of transient motion cueing drive schemes, it was considered extremely important to be able to employ very responsive hardware as the starting point and then to experimentally degrade the response to that level wherein transient cueing concepts are noticeably and adversely affected.

With the foregoing desired hardware and drive concept improvements in mind, it was concluded that a g-cueing system research test bed was required in order to develop a g-cueing system with the optimum cost/capability tradeoff as well as specifications for future operational systems. Certain specific objectives were established for the development of a device called the Advanced Low Cost g-Cueing System (ALCOGS):

1. Bring seat, suit, and shaker together as one integrated system with common control

2. Improve the response characteristics of primarily the g-seat, and secondarily the g-suit, over those existing in today's operational seat/suit systems.

3. Incorporate close-loop servo operation in order to provide an accurate means for measuring system outputs which produce a given cue.

4. Investigate, develop, and embody within the final system mechanical concepts which improve the somatic cueing quality of the g-seat over that available in the first generation of g-seat approach.

5. Broaden the resultant hardware and software design to accommodate F-16-type tilt-back seat configurations as well as the more conventional upright seat configurations associated with the F-15 and other aircraft.

6. Attempt to design this system so as to lower the aggregate cost of a seat/suit/shaker system.

7. Build and deliver a system with the above characteristics as well as a software drive module to support further research and development.

The ALCOGS was delivered to AFHRL at Wright-Patterson AFB, Ohio, and was accepted in late 1977. Several pictures of the system are provided (Figures 4, 5 and 6). The most noticeable changes from the first generation g-seat are:

Figure 4. **Advanced g-cueing systems.**
This second generation g-seat was also developed for AFHRL by the Singer Co. – Link Division and employs hydraulic actuators instead of pneumatic actuators for better response. The seat was developed for tactical aircraft simulators.

1. The departure from a mosaic element cushion approach, but the retention of cushion attitudinal and elevation change capability.

2. The implementation of thin cushion surface bladders for localized pressure and tactile area-of-contact stimuli generation.

3. Hydraulic actuator servo systems to provide the desired response characteristics.

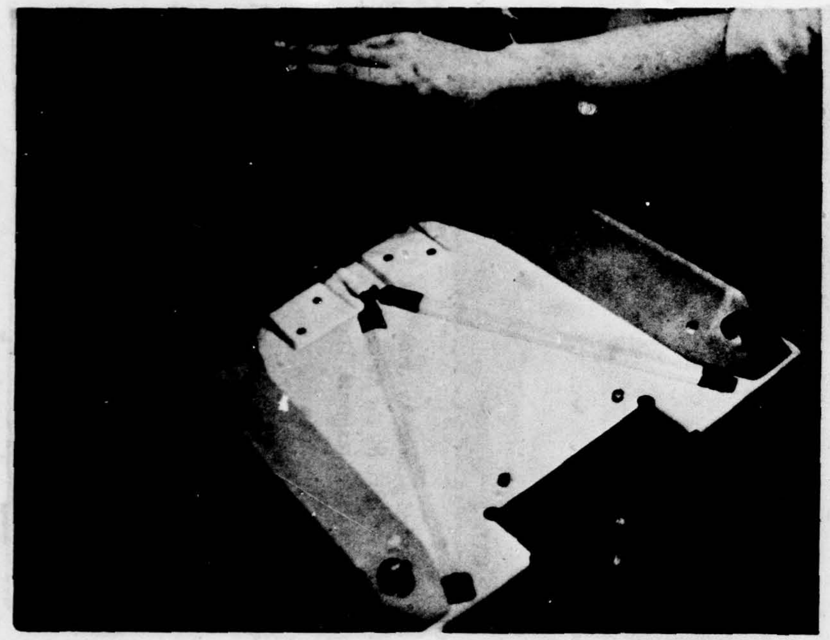

Figure 5. **Exposed seat pan of advanced seat.**
The advanced seat pan and backrest planes are driven in roll, pitch and heave. Inflatable rubber bladders overlay these planes. The seat pan has passive thigh ramps (pictured) and tuberosity stimulating blocks.

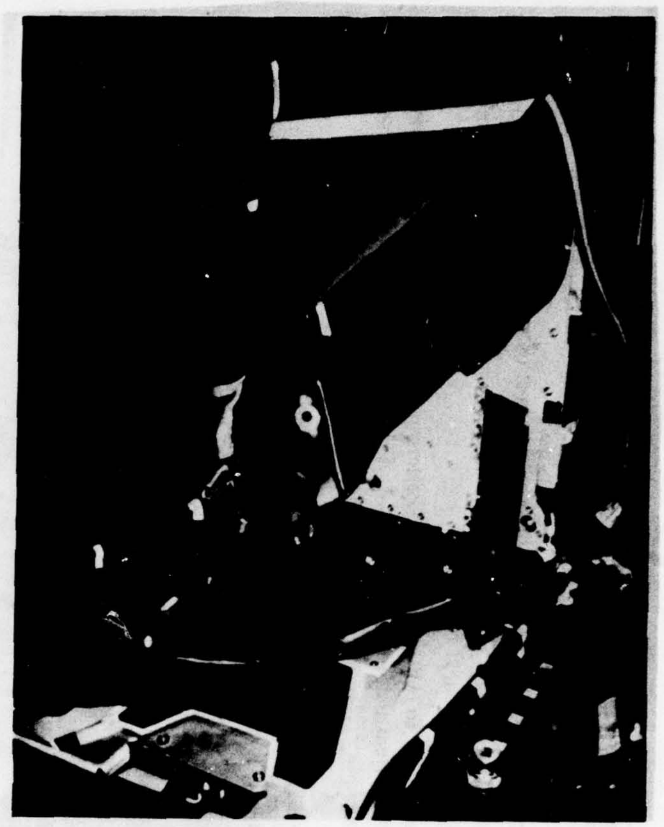

Figure 6. **Advanced g-seat exposed.**
The slip covers and firmness cells have been folded back to reveal the seat pan and backrest planes. The backrest also has left and right radial elements which are flaps at the base. These elements stimulate the lower back.

4. Adoption of passive rather than active seat pan thigh panels.

5. The implementation of lower backrest radial elements to provide strong area-of-contact cues for vertical and longitudinal acceleration.

6. Differential lap belt drive for inclusion of lateral as well as longitudinal and vertical belt cueing.

7. The addition of a seat pan longitudinal degree of freedom cascaded on seat pan cushion pitch, roll, and heave.

The ALCOGS g-seat cushion assemblies are mounted in a replica of the F-15 seat frame, which in turn is mounted on a test bed frame that can be either inserted into a laboratory version T-38 simulator cockpit or left free-standing external to the cockpit. The seat frame is supported on the test bed frame by linkages which permit the seat to be oriented at any angle of inclination between those employed by the F-15 and F-16 seats. The seat frame is pinned to the test bed so as to permit the frame to be vibrated by a seat shaker actuator at ±1/2g in the 4.5 to 40 Hz range. Buffet and other vibratory effects may be displayed by the seat frame shaker or, alternately, by the seat pan cushion itself. The suitability of the latter will determine whether the role of the seat frame shaker may be absorbed by the g-seat and whether the seat frame shaker system can be totally eliminated from future g-cueing systems.

The g-suit features press-to-test and pressure/g instructor inputs which are handled all-electronically rather than by mechanical and software means, respectively. A high volume pneumatic servovalve design serviced by compressed air and vacuum provide more rapid suit pressurization and exhaust than are available, for example, in the suits built for the Simulator for Air-to-Air Combat (SAAC) and the F-4E18 simulator.

Similar to many other motion system installations, the ALCOGS is supported by an electronics control cabinet which houses the electronics associated with the system control logic and the 16 servo loops. The electronics control cabinet permits system operation in a "maintenance" mode wherein the servos may be driven manually or by two software drive modes; i.e., one wherein system control is maintained at the location of the electronics cabinet, and a second wherein system control is transferred to a remote location such as a simulator instructor/operator station. The electronics cabinet employs two variable frequency oscillators to permit the genration of superimposed vibratory effects at any frequency in the 4.5 to 40 Hz region. A discrete "bump" channel is further superimposed on the vibratory output. The electronics cabinet also controls the activity of the system pumping station wherein hydraulic, pneumatic compressor, vacuum pumps, and associated reservoirs are located.

The primary design problems faced were centered in the g-seat system and in two areas: system response and packaging. The g-seat specification called for seat pan and backrest cushion excursion of 6.35 cm and a rise time of all servo actuators of 30 ms or less. The latter implies a system bandpass of 10 Hz or an order of magnitude larger than that available in the first generation g-seat. The bandpass objective necessitated the use of hydraulic actuators and, to ensure that hydraulic resonant frequencies are maintained well above the bandpass frequency, servovalve mounting in close proximity to the actuator.

Even more challenging, the same 30 ms rise time objective was sought in the cushion pneumatic surface bladders (firmness bladders) overlaying both seat pan and backrest cushions. A dual compartment (right and left) bladder is employed on the seat pan and a single compartment bladder is employed on the backrest. Although only 2.54 cm thick when inflated, these bladders represent significant volumes. Based on the function of the bladders, pressure and tactile area of contact stimuli generation induced by depressurization and resultant flesh contact with the undersurface supporting the bladders, it was felt the driving medium must be air. After considerable searching and testing, a two-stage pneumatic servovalve assembly was developed which can handle the large air volume at the desired 30 ms rise time objective.

It is apparent that the response design objective required the utilization of servoactuators considerably more mechanically sophisticated than those employed in the first generation g-seat. System cost reduction could be realized, therefore, only if the cushion assemblies could be packaged in such a manner as to permit a broad application to many different seat styles with minimum redesign. A design objective then was to package the cushion assemblies within volumes commensurate with those occupied by the standard seat cushion, survival kit and parachute pack. This task was made difficult by the number of actuators employed, the fact that these actuators are hydraulic, the desire to keep actuator and servovalve in close proximity to one another, and the 6.35 cm cushion stroke requirement coupled with ram end cushion capability. The resultant design packages five servo systems in a backrest assembly which is approximately 38 by 53 by 9.5 cm in dimension. The seat pan assembly packages six servo systems in a volume approximately 38 by 38 by 15 cm in dimension. A modular design approach has been employed in the actuator assemblies themselves in order to permit actuator set up and service. The ALCOGS performance capabilities are shown in Table 1.

Table 1. **ALCOGS Performance Capabilities**

Component	Axis	Excursion	Response
Seat Pan	Roll, Pitch	±12°	10 Hz
	Heave	±3.175 cm	
	Fore-Aft	±2.54 cm	
Backrest	Pitch	±6°	10 Hz
	Yaw	±9°	
	Surge	±3.175 cm	
Seat/Backrest Bladders	Roll, Heave, Surge	2.54 cm	6 Hz
Seat Shaker	Heave	±.635 cm	34 Hz
Lap Belt	Fore-Aft, Roll	±3.81 cm	10 Hz

The ALCOGS system has been integrated with the AFHRL Simulation and Training Advanced Research System (STARS) complex at Wright-Patterson AFB. It is being used in an engineering and psychophysical test, evaluation, and development program, with the primary objective being the determination of the optimum seat g-cueing hardware and drive algorithms for use in tactical aircraft simulators. The program will involve: (a) A complete characterization of the system performance by individual axes and combined axes to assess synergistic effects; (b) psychophysical evaluation of static and dynamic cueing capability using the full range of seat performance and initially postulated and implemented drive algorithms; (c) further development and refinement of drive algorithms using psychophysical experimental test and evaluation techniques (both sustained and onset algorithms for the conventional and tilt-back (F-16) aircraft seat configurations will be developed. The onset cueing algorithm development will investigate washout techniques to possibly extend the range of seat onset cueing capability); and (d) and investigation of the effects of degraded hardware performance (excursion and frequency response) on cueing capability. Also buffet induced through the seat pan versus buffet through the seat shaker will be investigated. The final product is to be a specification for minimum seat hardware and optimized drive algorithms to be used in the procurement of future seat cueing systems for operational tactical aircraft training simulators. These activities will be performed throughout 1978 and early 1979. This technology will be of prime importance to such simulator programs as the A-10 and F-16 and to future g-cueing system retrofit programs.

High-g Augmentation Device Study

As mentioned earlier, the g-seat may be considered a mid-range g-level cueing device. Newly developed tactical aircraft exercise a flight regime wherein high-g loading is more often experienced and the physiological stimuli associated with this condition may gain importance in aircraft maneuvering control patterns. Based on this, it is appropriate to commence consideration of the types of simulator systems which might provide high-g effect stimuli (Figure 7).

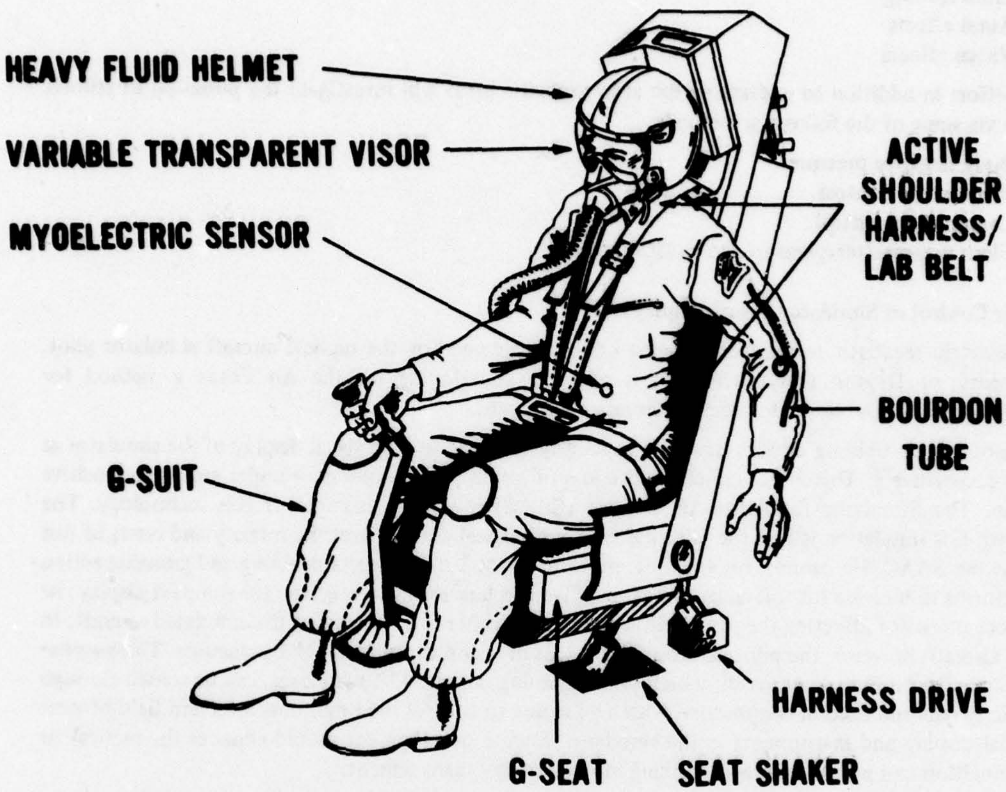

Figure 7. **Future high-g simulation devices.**
Devices other than g-seat, g-suit, and seat shaker devices are being designed for the tactical aircraft simulator environment. Mechanisms for loading the helmet, limbs and torso of the pilot are shown above.

A combined AFHRL/Massachusetts Institute of Technology/Link effort is currently studying potential force simulation systems in an attempt to identify those systems which

1. Are likely to produce stimuli important to high-g maneuvering control.

2. Are able to create encumbrances in the simulator equivalent to those experienced in the actual high-g flight environment.

3. Appear to be able to generate stimuli artifically in a 1g environment by means which are safe and which are acceptable to operational pilots.

The current effort is a study leading to characterization of the type of hardware/software systems required to produce the desired end effect. The system characterization is to form the foundation for eventual construction of experimental systems to determine the adequacy and usefulness of the simulation stimuli source.

The study will attempt to set forth the most reasonable methods of generating g-loading stimuli in the following areas:

1. Shoulder harness
2. Head/helmet coupling

3. Limb loading
4. Aural effects
5. Visual effects

The effort in addition to addressing the above specific areas will investigate the potential of stimuli production via some of the following methods:

1. Body negative pressure
2. Respiratory control
3. Lacrimation control
4. Flesh pressure/temperature interrelationships

Myoelectric Control of Simulator Visual Displays

Myoelectric feedback techniques are also being considered for the tactical aircraft simulator pilot. The University of Dayton (Dayton, Ohio) is currently developing for the Air Force a method for myoelectric control of the simulator cockpit visual environment.

State-of-the-art training devices have the capability for dimming the visual display of the simulator as a function of positive g. This effect simulates the loss of vision pilots experience under very high, positive acceleration. The Simulator for Air-to-Air Combat (SAAC) is a good example of this technology. The problem with this simulation is that the pilot has no physiological control over the intesity and onset of this dimming in the SAAC. He cannot, for example, perform the M-1 maneuver (a straining and grunting action a pilot performs to increase his tolerance to high positive acceleration) and brighten the dimmed display; he has no direct means of affecting the display in the simulator other than unloading the simulated aircraft. In the actual aircraft, however, the pilot can control the loss of vision through the M-1 maneuver. The purpose of this effort is to develop a means by which pilot straining, via the M-1 maneuver, can be sensed through myoelectric signals and used in conjunction with a g-loading to control the brightness level and field-of-view of the visual display and instruments in the simulator. Such a development should enhance the tactical air combat simualtion and provide valuable training in pilot energy management.

This effect encompasses the design and development of a model implemented in software and associated hardware for the myoelectric control of acceleration induced dimming of the simulator pilot's visual display and instruments (Figure 8). To accomplish this, two algorithms are being developed. One will be a dynamic algorithm of the human visual system which will be driven by the pilot's g-environment. The

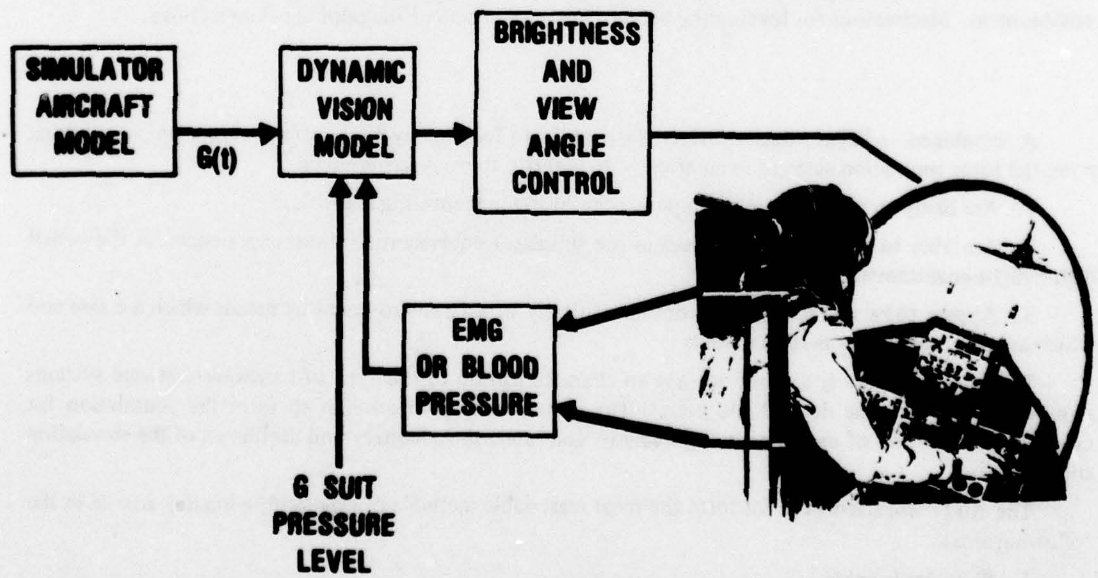

Figure 8. **Electromyographic feedback control of simulator visual system dimming.**
A more realistic method of simulating the physiological effects of increased g is being developed by AFHRL. The simulator pilot is in the loop and can control dimming or loss of his display by virtue of how well he performs the M-1 maneuver.

other will be an algorithm to predict the effectiveness of the pilot's M-1 maneuver, which will be driven by electromyographic potentials from selected muscle groups. The outputs from these two algorithms will be integrated to drive a brightness and visual field-of-view for the visual display and cockpit instruments. The integrated system will be implemented at the AFHRL STARS facility on the T-38 simulator. If successful, the system may be implemented on the SAAC and other Air Force tactical simulators.

III. CONCLUSIONS

Data base development efforts, which are in process, have provided a better understanding of the type of motion and force cueing required for Air Force tactical aircraft simulators and the type of devices necessary to effectively and efficiently provide this cueing. An advanced g-cueing system has been developed which provides both rapid onset and sustained cueing. It is capable of stimulating the important tactile and pressure, as well as some nonvestibular proprioceptive, human sensory modalities throughout the frequency spectrum and for the duration of motion and force cueing presented during most tactical flight maneuvers. High-g augmentation devices are also being investigated and designed which should efficiently provide some of the additional cueing present during extremely high-g flight environments.

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