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Development of Multisensory Orientation Technology for Reducing Spatial Disorientation Mishaps

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Air Force Research Laboratory
Human Effectiveness Directorate
Biosciences and Protection Division
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NOTICE AND SIGNATURE PAGE

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

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FOR THE DIRECTOR

//Signed//

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The Air Force regards Spatial Disorientation (SD) and loss of situational awareness (SA) as contributing factors in operational Class A ($1M in aircraft loss and/or pilot fatality) aircraft mishaps. Multisensory systems have been developed to enhance the aircraft attitude information to the pilot. The systems incorporate multisensory aids including helmet-mounted symbology and tactile and audio cues. Two systems have been prototyped and demonstrated in the Air Force Research Laboratory. The technology could have application in the rotary-wing brownout program. This paper discusses the development of two systems and a potential application including an augmented cognition application. Unlike automatic ground collision avoidance systems, these systems do not take over the aircraft if a pre-set altitude is broached by the pilot; rather, these multisensory systems provide complementary attitude cues to the pilot via the tactile, audio, and visual systems that allow the pilot to continue flying through disorienting conditions.

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1. 0 SUMMARY

The Air Force regards Spatial Disorientation (SD) and loss of situational awareness (SA) as contributing factors in operational Class A ($1M in aircraft loss and/or pilot fatality) aircraft mishaps. Spatial Disorientation (SD) is defined as an incorrect sense in-flight of one's position, motion, or attitude with respect to the earth's surface (14). Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (14). Multisensory systems have been developed to enhance the aircraft attitude information to the pilot. The systems incorporate multisensory aids including helmet-mounted symbology and tactile and audio cues. Two systems have been prototyped and demonstrated in the Air Force Research Laboratory. The technology could have application in the rotary-wing brownout program. This paper discusses the development of two systems and a potential application including an augmented cognition application. Unlike automatic ground collision avoidance systems, these systems do not take over the aircraft if a pre-set altitude is broached by the pilot; rather, these multisensory systems provide complementary attitude cues to the pilot via the tactile, audio, and visual systems that allow the pilot to continue flying through disorienting conditions.

2.0 INTRODUCTION

Current attitude information is presented to the pilot by the head-up display (HUD) and head-down displays (HDD). The primary flight instruments (HDD) have changed very little over the past 75 years. Pilots are still trained to "get onto the round dials" when they are disoriented or looking for reliable aircraft attitude information in flight. The standard head-down displays include the altimeter, airspeed indicator, heading indicator, and attitude display, which are arranged in a "T" formation. This arrangement allows the pilot to quickly scan these instruments and determine altitude, airspeed, heading, and aircraft attitude (pitch/bank). The MIL-STD HUD is characterized by MIL-STD-1787C

(11). In the HUD, a pitch ladder symbology set is provided that moves up and down with pitch and bank of the aircraft. The HUD is a fixed, see-through combiner glass mounted in the cockpit on the glare shield just above the HDD. Symbology is displayed as a virtual image on the glass, which allows the pilot to read the flight reference information with his/her eyes focused at infinity (> 20 feet).

Helmet-mounted displays (HMDs) are becoming more operationally capable and integrated into more and more fixed-wing aircraft such as the F/A-18 and the F-35 Joint Strike Fighter (JSF). The JSF program office is looking into a replacement for the hard-mounted HUD in the cockpit. MIL-STD-1787C symbology will be displayed on the visor of the JSF helmet. The challenge with HMDs is to provide information in the HMD that is compatible with the HDD. This information typically includes altitude, attitude, heading and pitch/bank information. One of the complaints about putting the current HUD information in the HMD is the excessive clutter of the climb-dive ladder with horizontal lines pitching and rolling throughout the limited field-of-view (FOV). HMD developers have devised an array of alternate attitude displays for the off-boresight attitude reference. When coupled with a head-tracking system, the HMD can display more detail-rich symbology on-boresight and less symbology when viewed off-boresight. The challenge to the HMD symbology developer is to develop both bank and climb-dive information in one display minus the disconcerting ladder lines streaming through the pilot's FOV. One concept in the F-35 is to display the MIL-STD-1787C HUD information on-boresight in the HMD, but to have it drop out of the display once the pilot looks off-boresight (>30 degs).

2.1 Spatial Orientation Retention Device (SORD)

The Spatial Orientation Retention Device, or SORD, is a multisensory cueing system that includes tactile, audio, and visual components that are integrated with a smart model of human orientation (Figure 1). The concept of SORD is to provide additional multisensory information to the pilot about his or her aircraft attitude (1). Many SD mishaps can be attributed to pilot distraction or channelized attention in flight, during which the aircraft slips into an unusual attitude so gradually as to remain undetected by the pilot's vestibular or somatosensory systems (14). In many instances, the aircraft crashes before the pilot realizes the unusual attitude. SORD provides tactile, audio, and visual information to the pilot in addition to the usual HDD or HUD attitude information already available. SORD is an alerting system for the pilot.

SORD has four components: tactile garment, 3-D audio, HMD symbology, and a Spatial Orientation (SO) assessor (Figure 1). The tactile garment, 3-D audio, and HMD symbology have been demonstrated in the Air Force Research Laboratory (AFRL). A prototype of a tactile cueing system incorporating electric tactors has also been evaluated. The tactile cueing system that has been evaluated is a vibro-mechanical tactor system. The 3-D audio system demonstrated is the NASA SLAB system which modulates the volume of white noise in either the left or right ear-cup depending on the direction of bank or roll of the aircraft (13). The off-boresight arc segment attitude reference (ASAR) symbology, also called the Non-Distributed Flight Reference (NDFR), allows the pilot to view attitude information off-boresight when the symbology is displayed on an HMD. The assessor is a mathematical model of human spatial orientation that runs in real-time in a microcomputer.

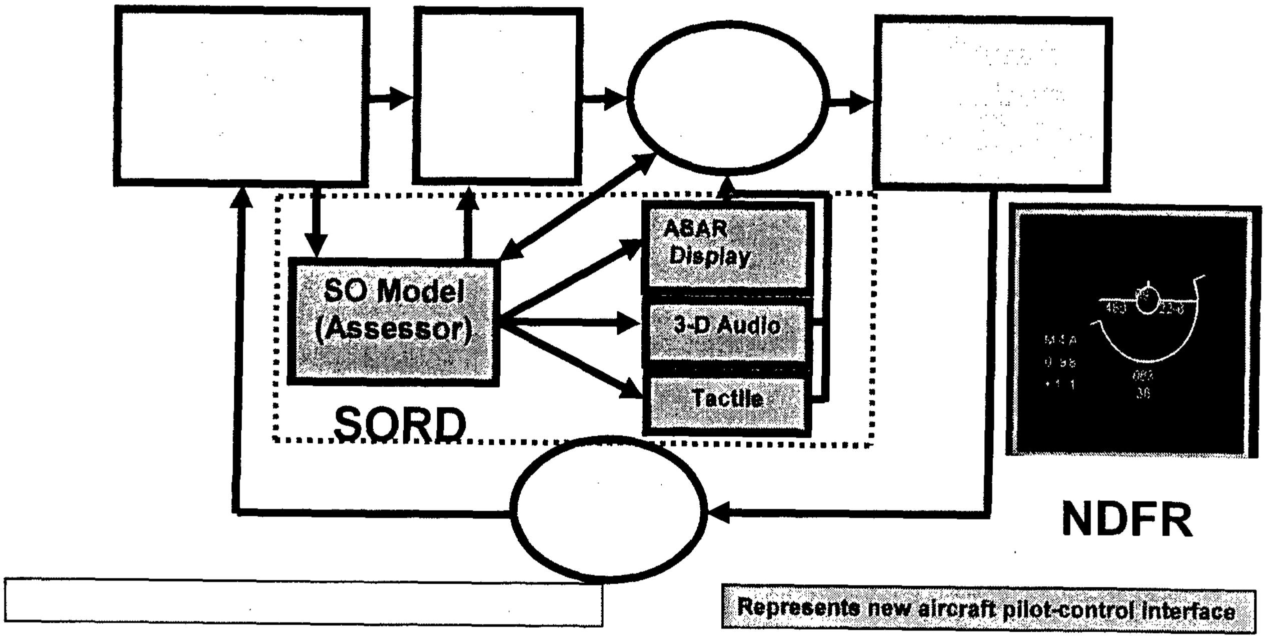

Figure 1. Traditional aircraft pilot-control loop with SORD shown in dashed area

2.2 Tactile Cueing

Tactile cueing is not new technology (5, 6, 15). It has been demonstrated extensively in the Tactile Situation Awareness System (TSAS) developed by the Naval Aeromedical Research Laboratory (NAMRL) and at TNO in the Netherlands (5, 6). Tactile torso displays consist of numerous vibrators or tactors that are in a matrix arrangement and have contact with the chest, back, and sides of the wearer. The tactile suits range in number of tactors from 8 to 64. The concept is to apply a mechanical or electrical signal to the skin of the wearer via this matrix of tactors in order to convey a signal or series of signals that have meaning, much like one taps a person on the shoulder in order to gain their attention. The tactors confer information to the wearer by presenting localized vibrations or electrical signals. By energizing a row of tactors, the horizon line can be emulated, completely encircling the wearer. By powering just one or several of the tactors, the pilot/wearer can be alerted to an over-banked situation such as a 30-deg roll to the left (Figure 2). The tactile cues that indicate over-banking of the simulated aircraft have been evaluated during emulated visual-vestibular illusions on the Dynamic Environment Simulator (DES) centrifuge, a dynamic flight simulator at AFRL.

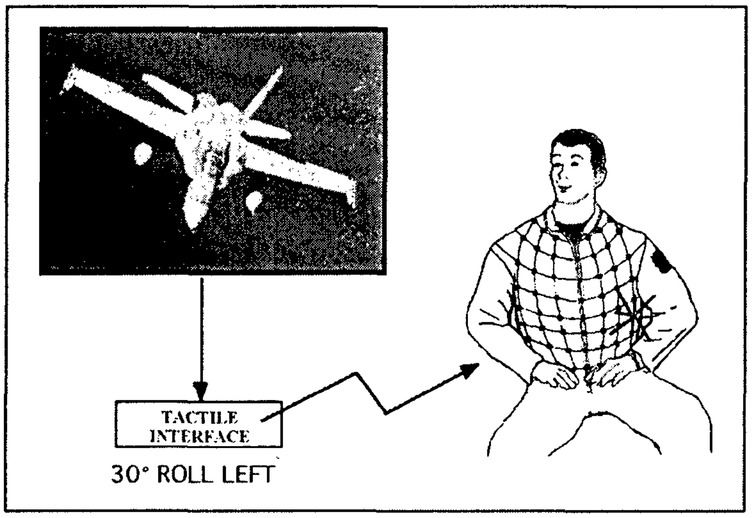

Figure 2. Localized tactile cue indicating a 30-degree bank to the left

2.3 3-D Audio

3-D audio is not a new technology. It has been demonstrated in the laboratory for 20 years and has been considered for operational aircraft (9, 10). The NASA SLAB is the audio cueing system implemented for the demonstration of SORD. SLAB is a real-time virtual acoustic environment rendering system that is available from the Spatial Auditory Displays Lab at NASA Ames Research Center (12, 13). SLAB performs spatial 3-D sound processing, allowing the arbitrary placement of sound sources in auditory space. SLAB is integrated with a Polhemus (Colchester VT) head tracker that provides head orientation information to the SLAB software. SLAB is currently being used with a white noise source that increases in volume as the subject rolls left (left-ear volume increases) or right (right-ear volume increases).

2.4 ASAR (NDFR)

The ASAR represents the visual display symbology that is being evaluated under the SORD program. In 1987 Dornier developed the ASAR as an alternate flight reference symbology to the standard HUD climb-dive ladder (3). The ASAR or "Orange Peel" display, as it has been called, has been demonstrated to accurately convey aircraft attitude information to the pilot without displaying the climb-dive ladder. The ASAR conveys dive angles by increasing the amount of attitude arc displayed to form a more complete circle. During climb, the attitude arc shrinks to indicate increasing climb angles until, at 90 degrees climb, only the ASAR gap marks remain (Figure 3). Bank angles are determined by comparing the center of the attitude arc to the aircraft symbol. The ASAR was modified to employ dots and gaps at +/- 30 degrees and +/- 60 degrees of climb-dive; the modified display is referred to as the Non-Distributed Flight Reference (NDFR) (7, 8). The advantages offered by the NDFR include its compact size and the ability to display it on an HMD off-boresight.

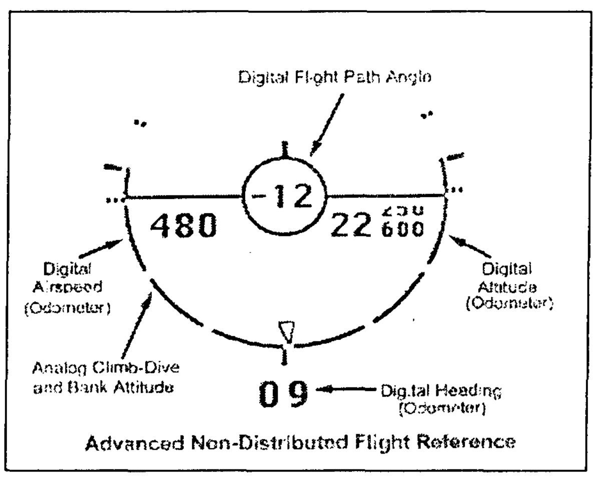

Figure 3. Advanced Non-Distributed Flight Reference (NDFR)

2.5 Smart Orientation Processor

The smart processor is the "brains" behind the multisensory cueing system. The Disorientation Analysis and Prediction System takes actual flight information (linear and rotational velocities and accelerations, aircraft attitude information, and airspeed/altitude) and processes these data through a visual-vestibular-tactile mathematical model of the human to develop an orientation prediction for the human (2). This prediction of orientation is compared to the actual aircraft orientation, and a difference between the model-predicted orientation and the actual orientation is developed. This difference is termed the "disorientation index" in the model.

2.6 Fixed Wing Applications

SORD has been demonstrated without the smart processor in the laboratory and in the DES centrifuge. The prototype SORD provides multisensory information via tactile cues on the subject's sides (over 30 degrees bank either right or left), auditory cues via the headset (volume changes as the simulated aircraft is banked), and the ASAR display which is displayed via an HMD that provides both a virtual image as well as a see-through capability. The ASAR provides aircraft attitude information (it displays what the nose of the aircraft is doing as one looks off-boresight) by interpreting the arc segment, its orientation, and its shape. The ASAR allows the subject to look for out-the-cockpit targets without having to look back inside the cockpit either to perform the "T crosscheck" or to interpret the hard-mounted HUD. The ASAR provides altitude, airspeed, pitch/bank and heading information all in one condensed symbol set (Figure 3).

When integrated with a smart processor (illustrated as the spatial orientation (SO) model assessor in Figure 1), SORD could operate in an active or "idle" state. If the pilot wanted SORD to be inactive, he/she would select SORD to be inactivated. When active, the assessor would begin comparing actual flight data with a computed spatial orientation model of the human. If the aircraft were banked more than a predetermined set point (e.g., > 30 degrees), the tactile cues would be activated (vibration on the side of the pilot), the 3-D audio would indicate a greater volume in one ear-cup vs. the other, and the ASAR symbology would indicate an over-banked condition. The smart assessor could determine when disorienting conditions are present in the cockpit and would implement the cueing strategy (tactile + audio, ASAR only, audio only, etc). The goal is to provide SORD technology for all military, commercial and general aviation cockpits.

2.7 Spatial Orientation Enhancement System (SOES)

The Spatial Orientation Enhancement System (SOES) was developed by Rockwell-Collins in conjunction with the Operator Performance Lab at the University of Iowa. Under a Dual Use Science & Technology effort with AFRL, the SOES was developed and evaluated at the Dynamic Environment Simulator centrifuge (AFRL/HEPG) as well as in flight in Canada (16). Only the DES evaluation is discussed here.

SOES included a tactile suit (Figure 4), an audio (sonification) system to provide orientation cues and a synthetic vision system to provide synthetic terrain when there was no out-the-window visibility. The contribution of these orientation aids was evaluated individually and in combination as subjects were presented with unusual attitudes in the DES and subjected to vestibular illusions.

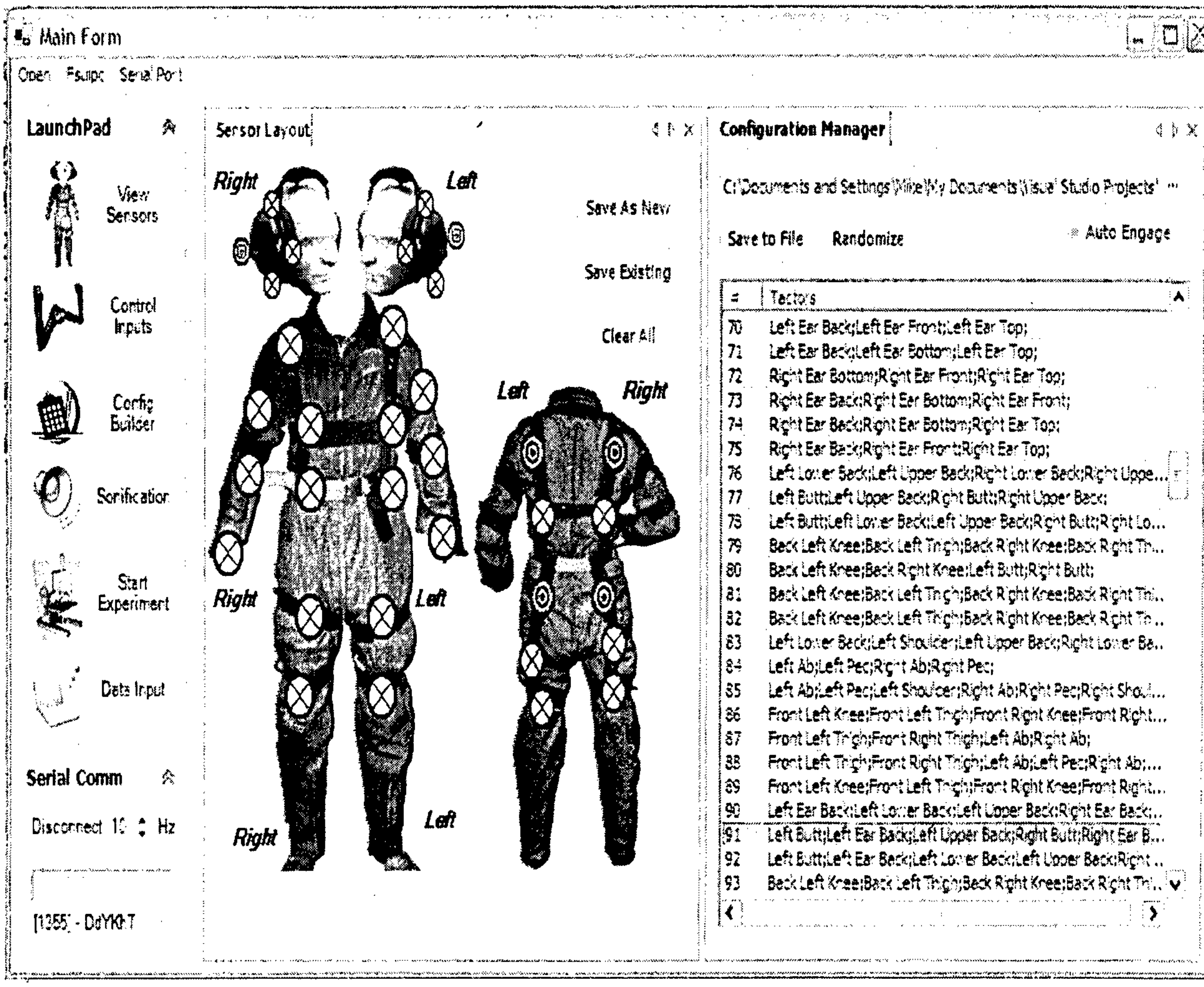

Figure 4. SOES tactile suit system

Figure 5. Subject with SOES

3.0 Methods

Twelve military pilots participated in the study. Eight were Visual Flight Rules qualified. After receiving a briefing and fixed-base simulator training, the subjects received training in the DES. A subject fitted with SOES is shown in Figure 5. The dependent variables were sonification (with/without), tactile cues (with/without), background attitude indicator (with/without), and synthetic vision display (with/without). Subjects were presented with a somatogravic illusion (pitch up and pitch down) and a leans illusion (left and right). Subjects experienced 12 exposures each. SOES was evaluated subjectively on a scale of 0 = low to 10 = high. Subjective ratings of the systems were tabulated (Figure 6).

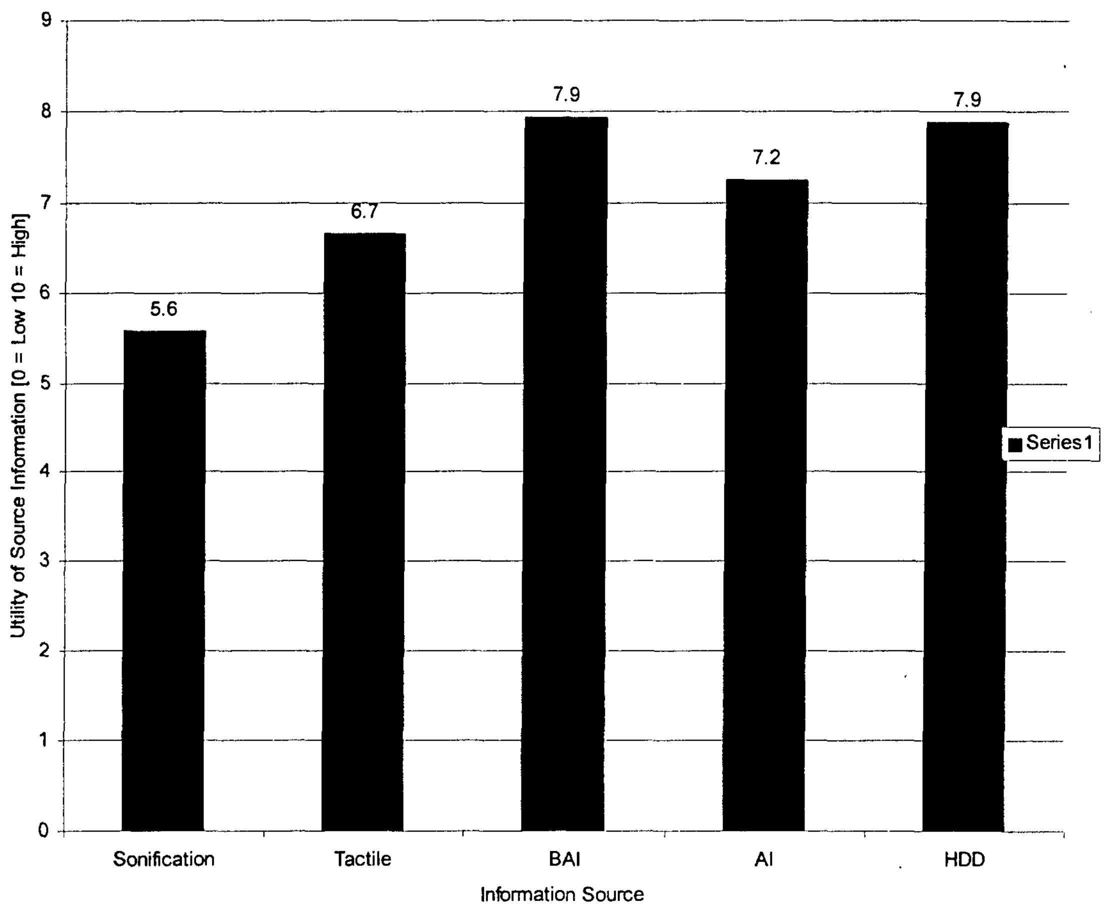

Figure 6. Subjective results of SOES in DES

4.0 Results and Discussion

Subjects rated the BAI, background attitude indicator (7.9) and HDD, head-down display (7.9) higher than the other displays. Sonification was rated the lowest (5.6), followed by the tactile suit (6.7) and the AI, attitude indicator (7.2). The DES was considered an excellent device for studying spatial orientation performance in flight environments by the researchers. Tactile and audio cues did not appear to be pre-cognitive without prolonged exposure and over-learning since some effort was required to "decode" the meaning of the tactors and sonification cues. The tactile cues did help reduce aileron reversals during recoveries from extreme bank angles; tactile cues also resulted in smaller pitch excursions and much smaller altitude gain/loss during recovery from extreme pitch angles. The sonification cues caused higher subjective workload in decoding and larger pitch excursions during recovery from extreme pitch angles.

4.1 Rotary Wing Applications of Orientation Enhancement Systems

SORD/SOES technology is also applicable to the helicopter flight environment. The tactile and audio cues can provide information to the pilot about helicopter attitude, crew resources, and situational awareness. An NDFR-like display on a helmet visor would be valuable to the helicopter pilot as it would provide critical helicopter attitude information as the pilot looks off-boresight. The 3-D audio cues would have two benefits: 1) the voice communications of ground control, the co-pilot, flight engineer and other crew in the rear of the helicopter can be spatially separated, allowing the pilot to hear the communication from the actual direction of the crewmember, thus reducing the pilot's workload; and 2) the communications from other helicopters can be tracked and presented to the pilot from their respective locations. If there is a multiple helicopter landing, the lead helicopter can communicate with the other helicopters and locate them audibly and spatially with respect to the lead's location. This would increase situational awareness during brownout landings when the helicopters cannot see one another. Tactile cues delivered via the seat pan would provide obstacle avoidance warning to the pilot.

4.2 Functional Brain Monitoring (ASOS)

The Augmented Spatial Orientation System (ASOS) is SORD or SOES with functional brain monitoring (electroencephalogram). ASOS will include a dry electrode ensemble that will be incorporated into the flight helmet. The electrodes will monitor the frequency of the EEG and a computer program will detect when the EEG is indicating an "overload" situation in the pilot. The EEG system will also be programmed to detect when Type II (recognized) illusions are detected. Gallimore et al. found significant EEG responses for two in-flight illusions during a simulator study involving Air Force pilots in a ground-based trainer (4). The functional state of the pilot will be monitored via the electroencephalogram. If the pilot is determined to be task loaded, or a pattern of electrode voltage signals a particular illusion, the multisensory cues to the pilot can be activated. If the aircraft were banked more than a predetermined set point (e.g., > 30 degrees), the tactile cues could be activated (vibration on the side of the pilot), the 3-D audio would indicate a greater volume in one ear-cup vs. the other, and the ASAR symbology would indicate an over-banked condition. The smart assessor could determine when disorienting conditions are present in the cockpit in conjunction with the brain monitoring system and would implement the cueing strategy (tactile + audio, ASAR only, audio only, etc).

5.0 Conclusion

A multisensory aircraft attitude tool is described that will allow the pilot to channelize his/her attention and spend more time on out-the-cockpit visual tasks without having to continuously bring his/her vision back into the cockpit to monitor aircraft attitude instruments. Aircraft attitude information currently displayed on HDD and HUD is supplemented by tactile cues, audio cues, helmet-mounted symbology or synthetic vision displays that reinforce attitude information about the state of the aircraft in real time. Tactile and audio cues give the pilot information about the airspeed, altitude, heading, and bank and pitch of the aircraft without having to constantly monitor in-cockpit HUD and HDD displays. The addition of functional brain monitoring will provide augmented cognition and help determine when the pilot is task loaded or experiencing disorientation. SORD and SOES can help reduce pilot workload by reassuring the pilot about his/her aircraft attitude and eliminating the requirement of having to focus on the cockpit displays. Potential application of the technology to the low/no visibility brownout problem is also under evaluation.

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