The Role of the United States Air Force Academy in the Spatial Disorientation Countermeasures Research Program

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INTRODUCTION

Spatial disorientation (SD) is a misperception of the attitude, position, or motion of an aircraft with respect to the ground or to other aircraft. SD continues to be a major contributor to Air Force mishaps, costing the Air Force $1.4 billion from 1992 – 2001. Twenty-eight aircraft were lost during this time, and the mishap rate due to SD remained relatively constant at 0.3 Class A mishaps per 100,000 hours flown.

The Air Force Research Laboratory (AFRL) manages a spatial disorientation countermeasures research program. It involves technological countermeasures, education and training, and the development of a spatial disorientation retention device (SORD). Researchers at the United States Air Force Academy (USAFA) have teamed with AFRL to help investigate the SD problem.

USAFA is uniquely qualified to play an important role in researching the causes of and possible countermeasures to spatial disorientation. There is a large pool of potential subjects for research studies, including 4000 cadets and nearly 500 faculty and staff members. This subject pool contains a full range of flight backgrounds. Most lowerclassmen have little flight experience, while nearly 1000 develop some flying skills during the soaring program each year. Approximately 80 cadets take introductory flight training during their senior year, and dozens more obtain their private pilot's licenses on their own. Additionally, there are approximately 40 military officers at USAFA serving on the faculty with flying experience.

A critical aspect of the SORD is the Spatial Orientation Model, or the Assessor. In order to appropriately model a pilot's spatial orientation, basic research must still be accomplished. Currently, cupulometry studies are being conducted to help characterize the time constants of the semi-circular canals. Other research efforts involve assessing training and developing in flight spatial disorientation profiles using propeller driven aircraft. Each of these projects is aimed at helping the AFRL Spatial Disorientation Countermeasures Research Group.

BASIC RESEARCH EFFORTS TO PROVIDE MODELING INPUT PARAMETERS

Several research protocols are being conducted to investigate basic mechanisms of spatial disorientation. During rotation, the semicircular canals sense angular acceleration due to the relative motion between the canals (which are attached to the skull) and the fluid within the canals. As the head and body begin to spin, the canals move and the fluid lags behind due to its

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inertia. After spinning at a constant rate, friction between the fluid and the canal walls will cause the fluid to attain a velocity equal to that of the canals and the vestibular system will no longer register any motion. In the absence of visual or external motion cues, the person will feel like they have actually stopped rotating. Once the rotation actually does stop, the canals now become stationary, yet the inertia of the fluid causes it to continue moving. This now causes the person to feel like they are spinning in the opposite direction even though they are actually stationary. Measuring the time for this self-illusory sensation to stop is known as cupulometry.

While many studies have been performed to investigate the time constant during rotation about the yaw axis, none have been done to determine the time constant of the semicircular canal during off axis rotations. To perform this experiment, the General Aviation Trainer (GAT-II) was pitched up or down 12 degrees (see Figure 1), then spun about the vertical axis at rates of 50, 100, and 150 deg/sec (1). Preliminary results, which are shown in Figure 2, show that the time constant decreases when pitched forward or backward. A second study is underway to investigate the time constants when the GAT-II is rolled left and right at 20 degrees. The time constants from both of these studies will be used in vestibular models to help determine perceived attitudes after different motion inputs.

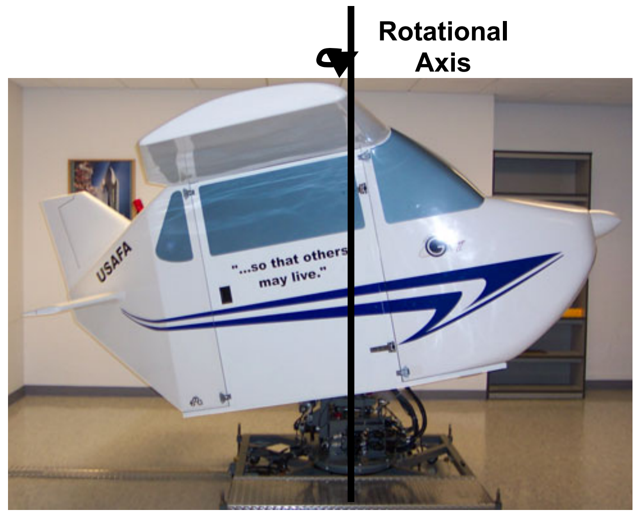

Figure 1. GAT-II pitched up 12 degrees during off axis cupulometry study.

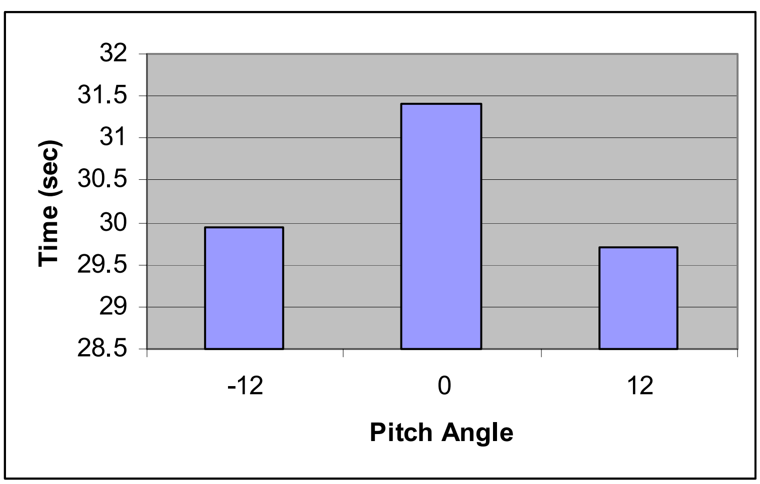

Figure 2. Time constant as a function of pitch angle.

Future cupulometry studies may be conducted to provide inputs to model the semicircular canals. Any number of initial orientations could be utilized to help characterize the vestibular system, and to help determine the limits of human variability. We are currently planning a study to determine how fatigue affects a person's sense of spatial orientation, and if pharmacological agents might alter these effects.

SPATIAL DISORIENTATION TRAINING RESEARCH

One of the most promising of all countermeasures involves training our aircrew to better understand spatial disorientation and how to counteract it when it is present. While textbook training can be useful, most researchers in the field feel that fliers really need to experience the physiological effects of SD. The most basic of all these experiences is the Barony chair, which has been used for years to demonstrate the Coriolis illusion and the decay of the semicircular response to constant angular velocity. Motion based flight simulators can also prove useful in pilot education; a current study within AFRL is attempting to quantify the usefulness of different devices. Finally, there is really no substitute for experiencing the illusions in an actual aircraft. Several studies have attempted to develop protocols for in flight illusions in fast moving aircraft and in the rotary community; the US Air Force Academy is investigating developing illusions in propeller driven aircraft.

A study was conducted (2) to evaluate the effectiveness of inducing spatial disorientation with profiles created by the manufacturer of the GAT-II. Thirty nine subjects volunteered; 11 cadets with their private pilot's license and 28 non-pilots. Three different illusions were tested: the Coriolis, the graveyard spin, and the leans. The subjects were asked: Rating from 'none' to 'very strong', what is your sensation of disorientation right now? [None; Mild; Medium; Strong; Very Strong]. As shown in Figure 3, it was found that the GAT-II produced a fairly strong Coriolis effect in subjects with no flying experience. The leans and the graveyard spin were also reasonably recreated, but to a lesser magnitude. There was no significant different between fliers and non-fliers.

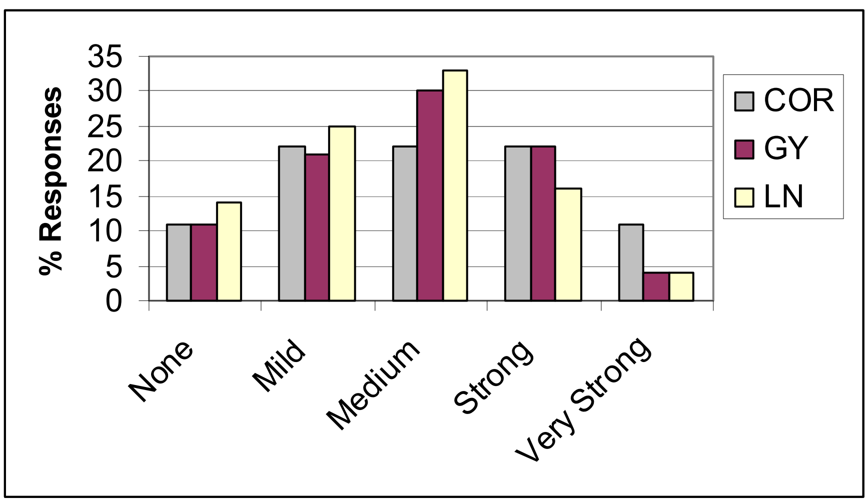

Figure 3. Percentage of responses for the Coriolis (COR), graveyard spin (GY) and leans (LN) to the question: What is your sensation of disorientation right now?

As mentioned previously, motion based simulators are only part of a complete training regimen. We feel that if pilots can experience illusions in flight at an early stage, they may be more likely to avoid the deleterious consequences of SD later in their careers. The T-41 (see Figure 4), a military version of the Cessna 172, was used to develop in flight profiles to produce illusions in blindfolded subjects. These illusions can be used in introductory flight training for both military and civilian pilots. The following eight illusions were tested: Acceleration (AC), Deceleration (DC), Elevator (EL), False Climb While Turning (FC), False Dive While Turning (FD), Leans (LN), Tilt With Skid (TS), Post Roll (PR). Each subject provided continuous verbal feedback on their perception during the flight. At the end of the maneuver, they were given a statement such as "I feel pitched up" for the AC maneuver. They rated this on a Likert scale of 1 to 7, 7 indicating that the flight profile was very successful in creating the SD illusion. Overall results from our first seven subjects are shown in Table 1.

Figure 4. T-41 aircraft.

Table 1. Subjective results from seven different test subjects

	SD Illusions								Subject
Subject	**AC**	**DC**	**EL**	**FC**	**FD**	**LN**	**TS**	**PR**	**Avg**
#1	1	3	3	6	6	7	7	1	4.3
#2	6	6	4	1	1	6	1	2	3.4
#3	7	7	3	7	7	7	1	1	5.0
#4	1	7	7	6	7	7	6	7	6.0
#5	1	4	2	5	1	5	6	6	3.8
#6	5	1	6	6	1	7	5	5	4.5
#7	4	7	1	7	1	6	7	1	4.3
Profile Avg	3.6	5.0	3.7	5.4	3.4	6.4	4.7	3.3	

As can be seen, the Leans was the most successful illusion profile, while the Acceleration, False Dive, and Post Roll illusions were the least successful. This may be due to the properties of the Cessna; the aircraft cannot achieve high enough thrust to produce a strong somatogravic/pitch up sensation. During the Post Roll illusion, the Instructor Pilot occasionally rolled the aircraft too fast, which would preclude inducing the post rotatory sensation. In general, all subjects experienced at least two strong illusions, and few had more that two that didn't produce any sensation at all.

Finally, at USAFA we hope to help evaluate different versions of the SORD as they are developed. The SORD not only involves modeling the vestibular system to help determine when a pilot might be disoriented, but also includes activating different sensory displays to alert the pilot that he may be in a dangerous orientation. This may include visual display symbology, three dimensional audio, and vibrotactile cueing, as well as the automatic ground collision avoidance system or other automated control systems. USAFA has already completed a visual display symbology trial, is beginning to start another, and has recently purchased a tactile vest.

The non-distributed flight reference (NDFR) has been developed at AFRL, especially to provide attitude information on a head mounted display. The primary attitude indicator of the NDFR is based on the arc-segmented attitude reference (ASAR) display, or orange peel display. The very first study conducted in our laboratory compared the performance of three different visual displays: the ASAR; an inside-out display, similar to an F-15 Heads Up display; and an outside-in display, similar to a MIG display (see Figure 5). Cadet subjects were presented with an unusual attitude (e.g., rolled 135 degrees and pitched up 45 degrees) and told to recover to straight and level as quickly and as accurately as possible.

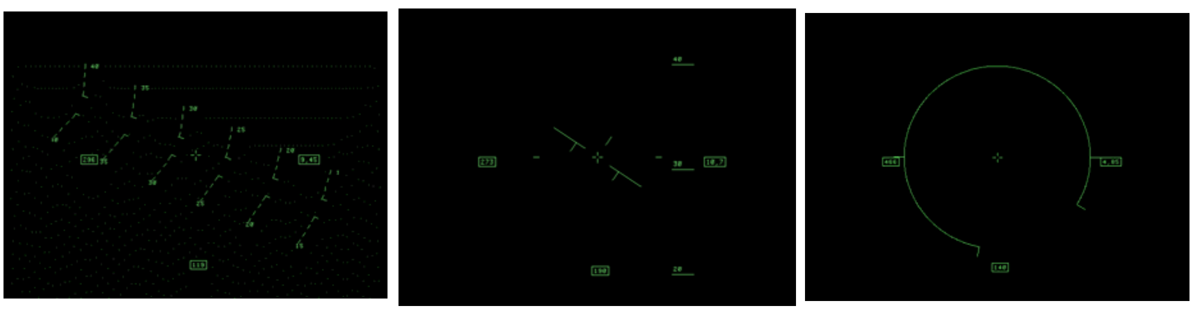

Figure 5. Typical F-15 type display (left), typical MIG display (center). arc segmented attitude reference display (right).

As shown in Figure 6, the arc-segmented attitude reference display exhibited the best time to initial stick input and had the fewest roll reversal errors (3). This indicates that the ASAR should be a strong candidate as the primary head mounted attitude indicator in future aircraft.

The US Air Force Academy has recently purchased a vibrotactile vest, which will also aid in the AFRL SD Countermeasures Program. This technology can be used to indicate a virtual horizon, display the location of enemy aircraft, provide hover information to rotary aircraft, or to indicate the desired heading. Many basic physiologic questions must be answered before fielding such a system: for orientation, is it better to provide a command or a descriptive signal? How many tactors are necessary to provide adequate stimuli? What are the most effective frequencies and amplitudes to apply to the vibrotactile actuators? These issues, along with actual flight testing in the GAT and the T-41, will all be addressed by USAFA researchers.

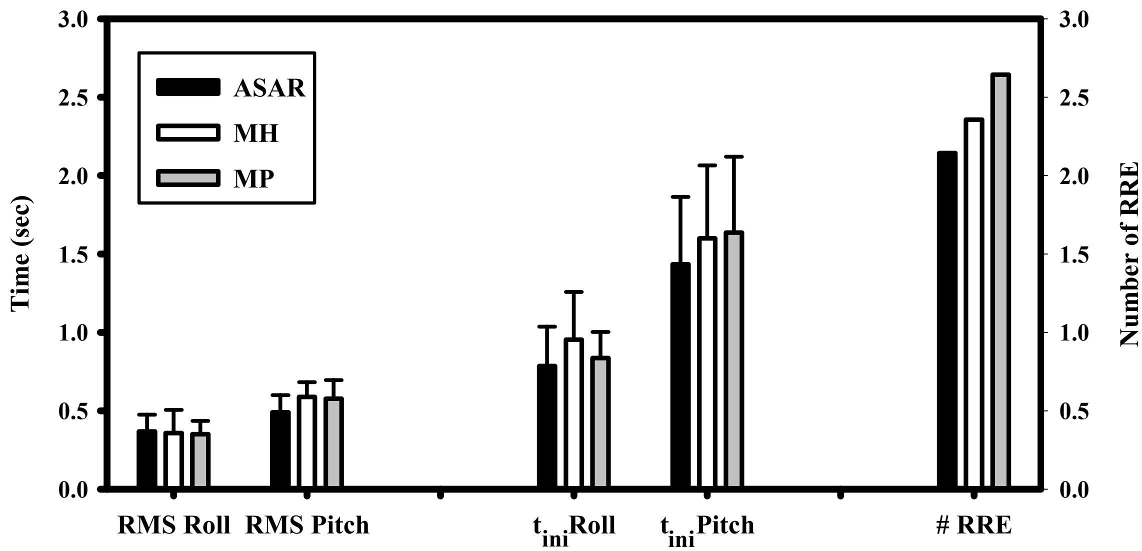

Figure 5. The RMS error in pitch and roll, the time to initial stick input, and the number of roll reversal errors for each display type.

CONCLUSIONS

The USAF Academy has incredible resources to help the AFRL SD Countermeasures Team accomplish its mission. Current members in our research group include a biomedical engineer, three physiologists, an expert in fatigue, human factors specialists, a nutritionist, and a pilot. The test subject pool is large, with a wide variety of experience. Finally, our facilities are excellent. We have the ability to perform desktop studies looking into display symbologies, follow-on experiments using a motion based simulator, as well as access to an instrumented propeller driven aircraft. By teaming with the AFRL SD Contermeasures Team, we hope to effectively battle the problem of spatial disorientation.

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Dr Brian Self is in his sixth year of teaching at the US Air Force Academy. Before joining academia, he spent four years working with the Air Force Research Laboratory researching issues such as sustained acceleration, personal protective equipment, and spatial disorientation. Other research interests include sports biomechanics, pedagogical techniques, and biomechanics.