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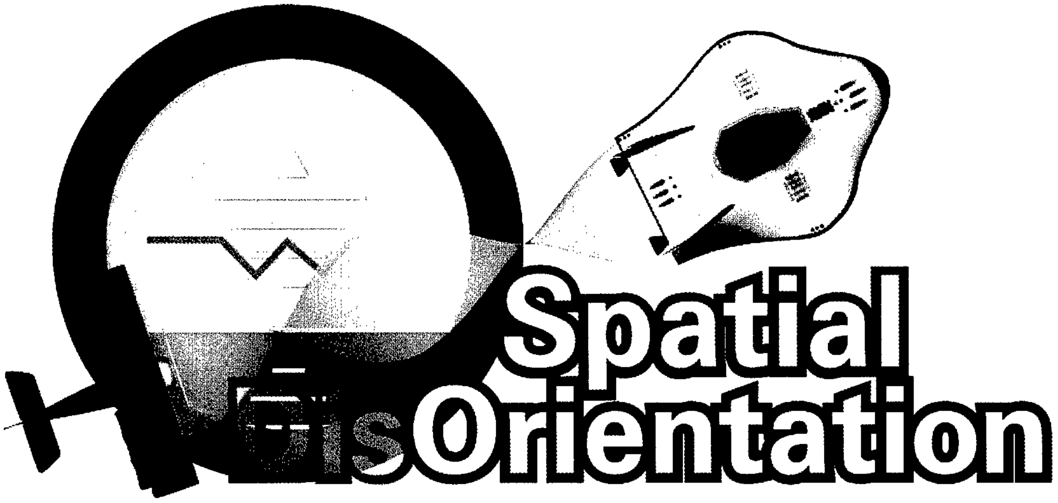
inside:

Special Issue: Spatial Disorientation Research



Spatial Disorientation Research

Major Todd Heinle

In the early days of aviation, the vast majority of accidents were the result of mechanical failure. As aviation matured and the technology improved, more and more mishaps could be assigned to a problem in the human end of the equation. At present, these human problems, or human factors, make up the majority of causes of aircraft mishaps. One of the principal human factors that are causal in mishaps is spatial disorientation (SD).

As shown in Figure 1 (see Page 2), which is drawn from USAF Safety Center data, the rate of USAF SD related mishaps per 100,000 flying hours changed little from 1991 to 2000. Study of the 20 years prior to this time reveals similar numbers. The data from the Army and Navy show similar findings, as do the FAA figures. For the USAF alone, this adds up to an average of $140 million annually. As a result of this, both the research community and operations personnel are working on methods of improving recognition of SD and developing better SD countermeasures.

The effort to reduce SD mishaps can be broken down into three general areas: improved training materials and techniques, development of technologies to minimize the occurrence of SD and assist in the recovery from SD, and research into the physiological mechanisms leading to SD. This three-pronged effort has led to numerous advances in the understanding of the causes of SD and its inter-relationship with both the cognitive process and the physiological makeup of the human body.

The training effort has looked at devices for the demonstration of SD on the ground, and more recently, specific flight profiles to demonstrate SD and instruct the student in SD countermeasures. The technological approach has contributed to SD training devices, but has had the most impact in the area of improved aircraft displays. These improved displays are intended to be more intuitive and therefore, will hopefully decrease the likelihood that the pilot will develop SD. Research into the physiological mechanisms of human orientation systems has led to increased understanding of the causes and countermeasures for SD.

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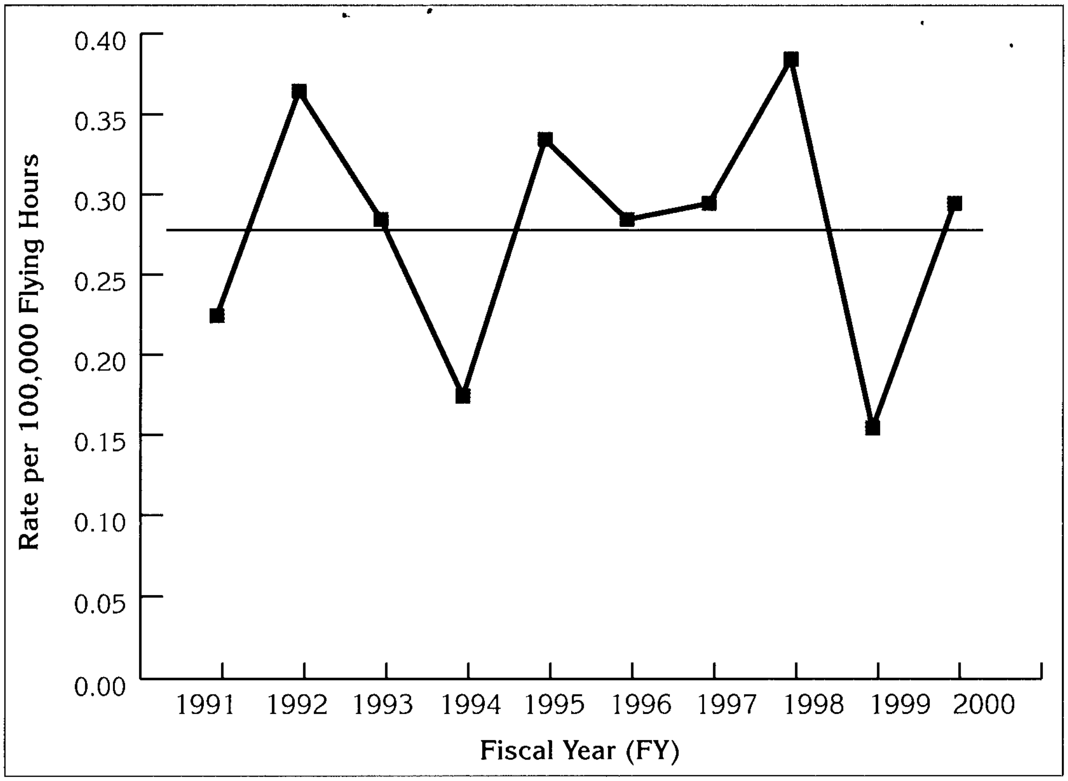

Figure 1. United States Air Force spatial disorientation mishap rate.

Internationally, SD is recognized as a very real danger to aviation and as such, many different nations are engaged in research activities designed to counter this threat. The U.S. Air Force Research Laboratory (AFRL) has initiated its Spatial Disorientation Countermeasures program, with research and development taking place in training, technology, and the understanding of the physiological mechanisms of SD. The Canadians have implemented a comprehensive training program for their aircrews. The Dutch are constructing a highly advanced device designed for both research and training. The Australians are concerned with the potential increases in SD brought about by new display technologies.

This is a complex issue that is extremely costly in lives and equipment. The resolution will not be easy, nor necessarily quick, but any reduction in SD mishaps can be considered a success in terms of lives saved and aircraft preserved.

This special issue of GATEWAY includes five articles that describe some of the SD training research, technological remedy development, and physiological research by many organizations. Collectively, these projects show the breadth of the recognition of the seriousness of this problem; they are advancing the science and technology information about SD; and they increase our expectations that the number of accidents will be reduced.■

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Glossary of Spatial Disorientation Terms

Autokinesis illusion	A dim light in a dark background, when stared at for 6–12 seconds, will give the illusion of motion (up to 20 degrees/second, and in one or several directions).
Barany Chair	A reduced-friction chair that is capable of near constant-velocity turning and is the most widely used ground-based demonstrator for angular SD illusions.
Blackhole approach	Caused by a lack of peripheral visual cues when flying an approach to a well-lighted runway at night surrounded by little or no other lighting. Causes pilots to fly lower than normal approaches.
Coriolis illusion	An illusion of angular motion (usually pitch or roll) that occurs when the head is removed from the plane of rotation; this illusion is also known as "cross-coupling" and is frequently associated with nausea, vomiting and other symptoms in naïve subjects.
Distance-Depth illusion	The misperception of distance due to any of a number of visual cues. Generally associated with objects that are learned to be a certain distance due to their size, and when a smaller similarly shaped object is seen at the same distance, the smaller size now makes the object to appear further away.
False horizon illusion	Misperception of the actual horizon caused by the presence of sloping terrain on or near the horizon, or strings of lights near the horizon, as on a well-lighted highway at night.
Flicker Vertigo	A confusion of the vestibular system usually associated with strobe lights or a light-flashing sequence between 5 and 20 Hz. Occurs primarily in helicopters.
G-excess illusion	An illusion that occurs when a pilot moves his or her head in a >1-G environment, which leads to excessive shearing of the otolith organs and to an exaggerated sensation of head, body, or aircraft tilt.
Leans	A feeling of being banked when the aircraft is actually upright and level; this illusion can be caused by both gravitoinertial forces (e.g., leveling out from a prolonged turn) or by visual factors (e.g., a sloping cloud-deck).
Leans illusion	A false perception of the horizontal plane resulting in the individual leaning away from true vertical to compensate.
Runway width illusion	A wider or narrower runway than expected by the pilot will give the illusion of being too low, on a wide runway, or too high, on a narrow runway.
Sloping runway illusion	The sloping runway gives the pilot the illusion of being too high or too low on approach, because his visual system has been trained to expect a flat runway.
Somatogyral illusion	A false sensation of rotation (or absence of rotation) that results from misperceiving the magnitude or direction of an actual rotation. This results from the inability of the semicircular canals to register accurately a prolonged rotation.
Spin recovery illusion	Another name for the somatogyral illusion.

Spatial Disorientation Acronyms

CFIT	Controlled Flight Into Terrain
G-LOC	G-induced Loss Of Consciousness
SA	Situational Awareness
LSA	Loss of Situational Awareness

Measuring the Head Tilt Illusion During Sustained Acceleration

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Spatial Disorientation (SD) has been known to adversely affect the performance of aircraft pilots even to the degree of disastrous accidents. There are many causes of SD, but most causes do not always produce disorientation. One reliable cause of disorienting illusions involves moving the head while exposed to sustained acceleration. This type of SD is caused by the Coriolis illusion, a false perception of rotation caused by stimulation of the semicircular canals in the ears. While any rapid head movement can cause mild sensation of motion, the sustained acceleration greatly magnifies the phenomenon. When an aircraft is flying straight and level, it experiences the same 1G acceleration that normal gravity exerts on us standing on the surface of the earth. When an aircraft turns, however, the turn causes the acceleration to increase. A high performance aircraft can produce 10Gs, or 10 times the normal gravity in a tight turn. If the induced G force is downward with respect to our body, we call it Gz; if toward our back, Gx; and if to the side, Gy.

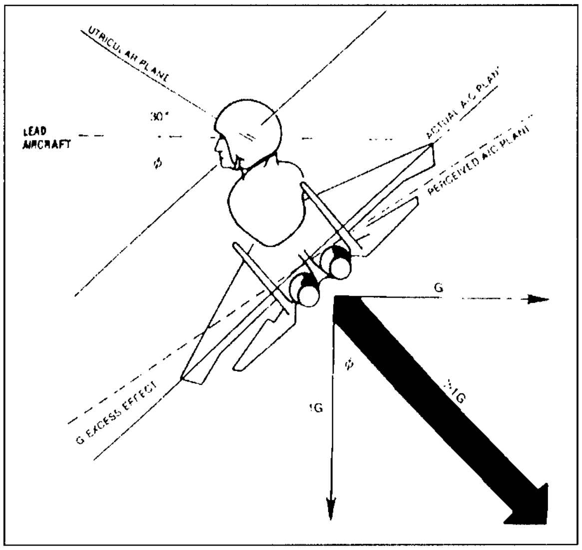

Figure 1. G-Excess effect and formation flying.

While in a prolonged coordinated turn, pilots often must look out of the cockpit to find other aircraft or survey a target. If the head is tilted with respect to the aircraft, and the aircraft is sustaining an acceleration greater than 1 Gz caused by the banked turn, the pilot has an illusion that the head is tilted more than it actually is, causing oversteering when coming out of the turn (see Figure 1). If a "correction" is made for this erroneous sensation, the pilot can overbank the aircraft. For example, formation flying may require a pilot to maintain a gaze up and to one side by 45°. During air-to-ground missions, pilots may turn their heads as much as 120° to follow a point on the ground. Aerial combat can frequently require the pilot to look directly behind him ("six-o'clock").

The G-excess illusion is believed to originate in the otolith organs of the inner ear. The human vestibular system is comprised of angular acceleration transducers (the semicircular canals) and longitudinal acceleration transducers (the otoliths). The objective of this research effort was to determine if the effect of head tilt in a greater than 1G environment on perception of attitude could be demonstrated and quantified using a ground based human centrifuge. The Air Force Research Lab (AFRL) has done extensive studies of the Coriolis illusion caused by sustained acceleration in its research centrifuge facility called the Dynamic Environment Simulator (DES).

Methods

The general method for this experiment was to collect a measure of the subject's perceived orientation while s/he was at a steady state G level and actively accomplishing some known head tilt. The greater than 1G environment was produced by a man-rated centrifuge and the head-aiming task was accomplished with a visual virtual reality system.

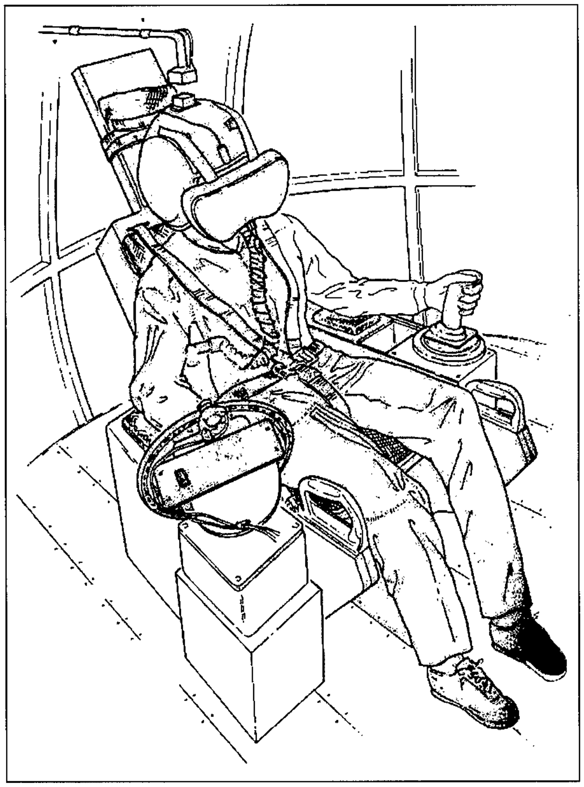

Figure 2. Virtual world of the research subject.

Collection of the subject's perceived orientation was accomplished using a device invented in-house and known as the Tactile Perceived Attitude Transducer (TPAT). This device consists of an aluminum hand plate with a glove suspended on the underside (see Figure 2). When the subject's hand is inserted into the glove, finger and wrist restraints secure the hand such that the back of the subject's hand is firmly affixed to the underside of the hand plate. The hand plate is mounted on gimbals so the orientation of the flat hand can be measured by potentiometers.

At the end of the DES centrifuge arm is a "cab" which houses a complete aircraft cockpit. Sitting in the aircraft seat inside the cab, the subject wore a head-mounted display with a field of view of approximately 90° horizontally and 90° vertically. On this display, the subject saw a computer-generated image similar to Figure 3 (see Page 6). One part of the image was a round target that the subject tracked by moving his/her head. The second element of the display was the cross-reticle in a square. Sensors on the helmet allowed its orientation in space to be measured, and the helmet orientation adjusted the location of the target disk so that it appeared to be fixed in space, regardless of head motion. The cross-reticle was in a fixed location, and moved with the helmet.

The amount of head movement was controlled by moving the target away from forward and the subject followed it with the reticle. After the target moved to the prescribed location, it remained stationary and began to blink for 12 seconds to allow the vestibular motion to stabilize. After 12 seconds when the blinking stopped, the subject adjusted the angle of horizon on the TPAT with the right hand and signaled completion by depressing a trigger switch with the left hand.

The experimental design had 84 combinations of independent variables: four cab pitch angles (-5° down, 0°, 5°, and 10° up) and four head pitch angles (-30° down, 0°, 30°, and 45° up), presented randomly. The acceleration levels were 1.0 (earth-normal), 1.4, 2.0, and 4.0 Gz. The three head yaw conditions were: 0° (forward), 45°, and 90° (right). To keep the rotation of the centrifuge from confounding the effects of head pitch and yaw, the seat inside the cab was rotated to the left the same number of degrees the subject was rotating the head to the right. In this way, the pitch axis of the head was maintained in the same plane as the cab axis so that an illusory tilt would be sensed in the same plane as an actual cab tilt. Each of these was repeated twice by each of the nine subjects (seven male, two female) for a total of 1,512 trials.

Results

To describe the relationship between actual and perceived head orientation, a number of linear and nonlinear modeling techniques were tried. The G-excess illusion is believed to be the excess tilt sensed beyond that accounted for by the tilt of the head/neck. Therefore, in predicting the magnitude of the illusion we assume the individual has self-knowledge of neck tilt. This must be subtracted from the sensed tilt.

This is represented in the two equations below. Using these models, head position accounted for a statistically significant component of the perceived attitude in both pitch and roll. In the roll axis, 92 percent of the variation in response (ground location perception) was accounted for by head position. Results in the pitch axis were also significant; however the data fit is not as good. Only 57 percent of the variation in response can be accounted for from head position. The nonlinear term

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(G0.25) was selected for the head tilt models because it consistently fit the data better than the other three proposed terms for the G-excess effect.

Magnitude of Roll Illusion (in degrees)

Roll illusion = 0.3397 x arcsin{(G0.25 - 1) x sin [head pitch] x sin[head yaw]}
Pitch illusion = 0.1491 x arcsin{(G0.25 - 1) x sin[head pitch] x cos[head yaw]}

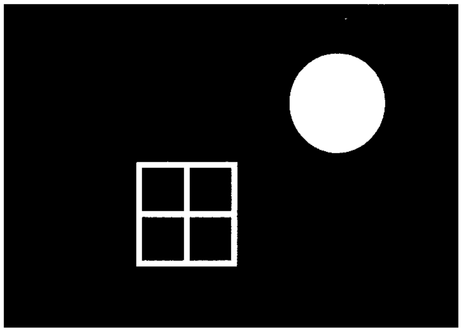
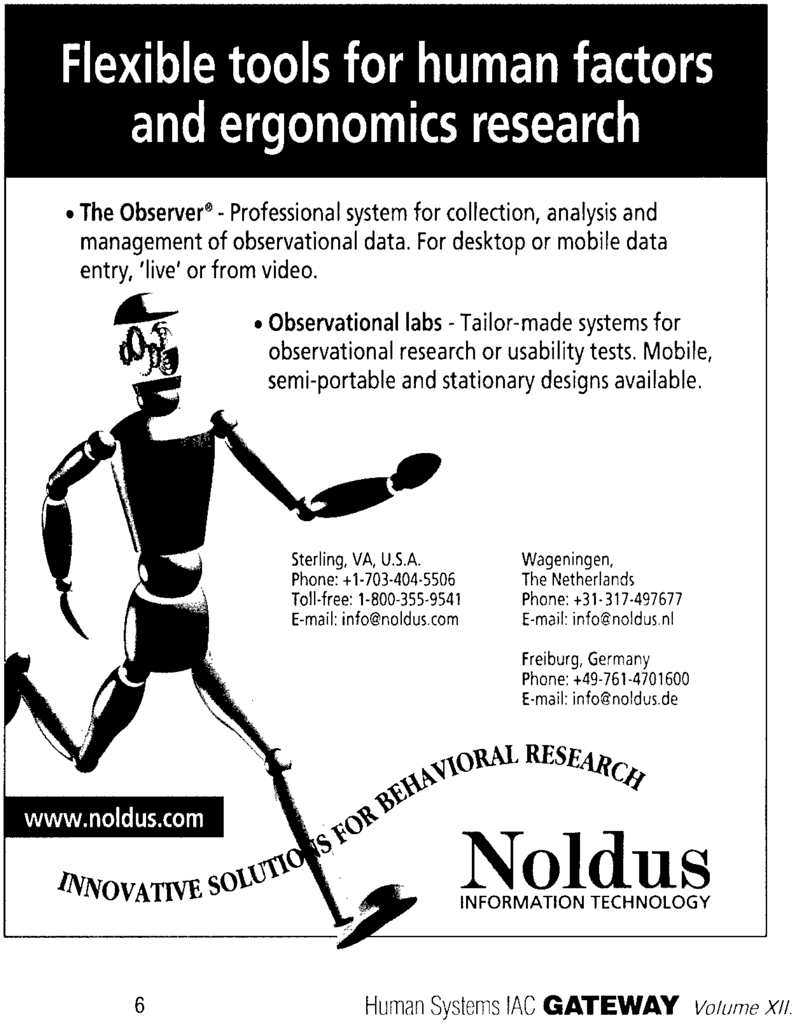


Figure 3. Task as viewed through the virtual reality goggles.



Conclusions

The data and models support the hypothesis that pitching and yawing the head while in a greater than 1G sustained acceleration can lead to a misperception of the attitude of the aircraft with respect to the earth. This illusion occurs in the pitch axis if the head is forward and translates to the roll axis as the head is turned toward one shoulder. Subjects demonstrated accurate awareness of true vehicle tilt up to 10°, but experienced significant distorting illusions of approximately 10° when the head tilted in the -30° to +45° range up to 4 Gz.

The magnitudes of illusions were greater for higher degrees of head movement and acceleration. However, physiological evidence of rate sensitive otolitic cells combined with in-flight evidence that supports sensitivity to rate of head movement necessitates the caveat that actual occurrence of the G-excess illusion may result in significantly larger transient illusory angles.

Recommendations

Pilots should be made aware of the possibility and magnitude of the G-excess effect. Training protocols should include the caveat that head pitches can cause erroneous sensations of under or overbanking of their aircraft. Special attention must be paid at low altitude to avoid disaster. Specifically, an upward head pitch combined with a head yaw into a turn, as is common in formation flying, can result in a sensation of underbank and a pitch-up of the aircraft. Intended corrective action actually overbanks the aircraft with a pitch down, causing loss of altitude. Downward head pitches during turning, as is common during bombing or strafing runs, can cause a sensation of overbanking. Intended corrective action actually underbanks the aircraft, causing altitude gain that could lead to midair collision when in formation flight.■

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Canadian Approach to
Spatial Disorientation Training

Dr. Bob Cheung

On Earth, our perception of position, motion and attitude with respect to gravity and the earth's surface is based on the neural integration of information from our vision, organ of balance, muscle and joint receptors, touch and pressure cues, and hearing. When exposed to flight environments under unfamiliar and changing gravitoinertial forces, information from some of these sensory systems is unreliable; therefore, pilots might experience spatial disorientation (SD). Research and technological initiatives that deal with SD require a great deal of effort and money to implement. However, training enhancements, where appropriate, can be more readily achieved and so should be addressed without delay. This article is a brief summary of SD training in the Canadian Forces.

At the undergraduate pilot level, trainees first encounter orientation and disorientation training during Basic Pilot Aeromedical Training or during High Altitude Indoctrination at the Canadian Forces School of Survival and Aeromedical Training in Winnipeg. The principal objective is to provide factual knowledge about spatial orientation and disorientation in flight, in a didactic lecture taught by trained aeromedical technicians. Ground based demonstrations of Coriolis illusion, spin recovery and false horizon are conducted using an unsophisticated flight simulator, the GYRO-IPT (Integrated Physiological Trainer, ETC Southampton, NJ). After completion of basic jet training, it is recommended that a comprehensive demonstration of other illusions should be given. These illusions include: somatogyral, closed loop spin recovery, leans, autokinesis, blackhole approach, runway width, and up-slope runway illusions. For the rotary wing, the demonstration also includes distance-depth perception, flicker vertigo and false horizon at night. For refresher training and within an operational flying squadron, it is encouraged that SD awareness should be raised by having experienced pilots list and discuss recurring SD situations that are specific to that aircraft type.

Traditionally, in-flight training includes the demonstration of unusual attitude recovery. The emphasis of the demonstration is on recovery, not the causes or solutions of disorientation. Although SD could conceivably occur during the recovery, it probably does not occur very often because the student expects an unusual attitude and has a clearly conceived set of options in his mind when he is given the task to right the aircraft. While ground-based training is helpful, it has been shown that demonstrations of SD within the actual flight environment are complementary to the ground-based training. In-flight demonstration consists of reinforcement of the limitation of the orientation senses in flight and the enhancement of aircrew awareness to potential SD situations. In addition, in-flight demonstrations also provide the trainee with a series of flight procedures to cope with disorienting circumstances and illusions. With the assistance of Col. Malcolm Braithwaite (Chief of United Kingdom Army Aviation Medical Corps), an avid proponent of in-flight SD demonstrations in the rotary wing, a series of in-flight demonstrations of SD in the helicopter were introduced to senior flight instructors at the Griffon Operational Training Squadron.

Although various technological measures show promise in combating disorientation training is the only practical solution to enhance SD awareness and countermeasures that can be achieved without delay.■

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calendar of events

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URL: http://www.ergoexpo.com

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A Coruna, Spain. April 15–18, 2002
Human Factors and Medicine Panel Symposium On Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures
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may

Montreal, Canada. May 5–9, 2002
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Spatial Disorientation, Geographic Disorientation, Loss of Situation Awareness, and Controlled Flight into Terrain

Bill Ercoline
Fred Previc

Spatial orientation and disorientation are commonly used terms in neurology and neuropsychology as well as aviation, and they mean different things to different professions. Someone who suffers from brain damage and is spatially disoriented, for example, may have an inability to tell right from left, or may have trouble finding their way around unfamiliar surroundings. This is not what spatial orientation refers to in the aviation environment, however. In the aviation world, spatial orientation mainly refers not to our position relative to particular places on earth but in relation to earth-fixed space in general. According to its most widely used definition, one that has been accepted by a large number of countries, spatial disorientation (SD) refers to:

> *[A failure] to sense correctly the position, motion or attitude of the aircraft or of him/herself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. (Benson, 1988).*

Added to this standard definition is the caveat that:

> *... errors in perception by pilots of their position, motion or attitude with respect to their aircraft, or their own aircraft relative to other aircraft, may also be embraced within a broader definition of spatial disorientation in flight. (Benson, 1988).*

What the above definition implies is that the inability to maintain one's orientation with respect to particular objects or places on the ground—e.g., landing at the wrong airport or other types of "getting lost"—do not fall within the definition of SD. Rather, such incidents would fall under the general category of geographical disorientation. Another way to view the distinction between spatial and geographical disorientation relates to the functions of the three major types of primary flight instruments, as described in Air Force Instruction 11-217: control (attitude and engine power/thrust), performance (altitude, airspeed, heading, vertical velocity, acceleration, angle-of-attack, and turn rate), and navigation instruments (bearing, range, latitude/longitude, time). Spatial orientation is maintained by means of the control and performance instruments, whereas geographical orientation is mostly maintained with reference to the navigational instruments (Gillingham & Previc, 1993). Although some definitions of SD do not include an erroneous perception of altitude (Navathe & Singh, 1994), misperception of altitude is clearly SD by the standard definition because it involves an erroneous sense of "position...within the fixed coordinate system provided by the surface of the earth and the gravitational vertical."

The second part of the definition goes beyond the problem of orienting in relation to earth-fixed space to include the perception of the pilot's relationship to his or her own aircraft—as in the "breakoff" and other phenomena in which the pilot may feel detached and flying from outside the aircraft—as well as parameters such as separation distance and closure rate relative to other aircraft. Misperception of these latter elements may or may not occur in association with other spatial orientation problems, and by no means should all mid-air collisions be listed as SD mishaps. However, some mid-airs may occur because the pilot is unaware of his or her own aircraft's velocity or trajectory in space—i.e., a manifestation of SD. How such SD-related mid-airs might occur is illustrated by the pilot of the second aircraft in a formation of two who, after refueling, attempted to maneuver his or her aircraft into a standard formation position behind and above lead. However, as the pilot established a cutoff angle on lead, while moving away from the tanker, he inadvertently allowed the aircraft to descend. The result was a mid-air collision with number two colliding with the lead aircraft, where two aircraft and several aircrew members were lost. Investigators were tasked to explain why the mishap aircraft would descend into lead. It appears the pilot of the mishap aircraft misperceived the lead aircraft as descending, when number two was actually descending. This occurred when the mishap aircraft slowly rolled out of the intercept bank. During the rollout, the pilot of the mishap aircraft misperceived the lead aircraft as descending, when the apparent movement of lead with respect to the mishap aircraft's canopy rail caused the perception of a descending lead. The mishap aircraft was only trying to follow lead. Because of this latter definition of SD, the resulting mid-air would have justifiably been considered an SD-related mishap. As might be expected, broadening the category of SD mishaps to include disorientation relative to other aircraft results in a large increase in the SD mishap rate (Neubauer, 2000).

What is termed SD today was not always referred as such. Until the 1970s, SD was also referred to as "aviator's vertigo" or "pilot vertigo," while spatial orientation was often referred to as "aerial equilibrium." The term "spatial orientation" appeared in a classic early text on instrument flight (Ocker & Crane, 1932), and the term "spatial disorientation" was used shortly thereafter (Macurdy, 1934). Although SD was a commonly used term by the 1950s, "vertigo" was still included in place of SD in aerospace medical textbooks until 1971 and in United States Air Force (USAF) mishap forms until 1989. Today, "vertigo" is recognized as a separate symptom—usually referring to dizziness, light-headedness ("giddiness" in the older literature), visual-field instability, or other physical or emotional sensations produced by the motions of flight—whereas SD is recognized as a phenomenon that can occur with or without such sensations. Indeed, all too many pilots have gone to their death never feeling or suspecting that anything was amiss with their aircraft's altitude or trajectory. What may be experienced during one type of SD may be very different than what is experienced during a different type, which begs the question as to the different types of SD.

There are three accepted types of SD—unrecognized, recognized, and incapacitation. Type I SD (unrecognized) is the most common and is usually associated with subthreshold motion, incomplete or failed instrument crosscheck, task saturation, or channelized attention. Type II SD (recognized) is the more traditional type of disorientation. It is associated with known conflicts between two or more of the sensory mechanisms related to spatial orientation (e.g., degraded vision and semicircular canal stimulation). The third type of SD (Type III) is known as incapacitating. This SD is the least known and least understood. It appears that under certain conditions the pilot of an aircraft can become so engrossed in a task that apparent stick inputs have no effect on aircraft control. The pilot is aware of the conflict, is physically trying to correct for it, but is unable to make the aircraft respond appropriately. Research has yet to quantify the causes of this type of SD.

Another related term that became widely used in the 1980s and 1990s is loss of situation awareness (LSA). This term, which dates back to World War II, was the subject of little research interest until the 1980s. It is a more general term than SD, as it refers to the loss of a pilot's "perception of the elements in the [aviation] environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1993). Because spatial orientation is undoubtedly a "key element in the aviation environment," spatial orientation is generally considered to be a subset of situation awareness (Gillingham, 1992; Previc, Yauch, DeVilbiss, Ercoline, & Sipes, 1995). Thus, any pilot suffering from SD also has LSA, although the reverse is not always true—e.g., a military pilot may lose his or her tactical sense and suffer from the threat of being shot down (and, by definition, LSA) without losing spatial orientation. Nevertheless, non-SD components of LSA can often precipitate SD, because the task of regaining LSA may divert the pilot's attentional resources and lead to a failure to properly crosscheck the flight instruments. The relationship between spatial orientation and situation awareness is shown in Figure 1 (see Page 12).

A final term that has been used in conjunction with SD is controlled-flight-into-terrain (CFIT) (Scott, 1996). While the vast majority of CFIT accidents involve a misjudgment of altitude (often during landing) and therefore should be classified as SD, some may be classified as geographical disorientation. If, for

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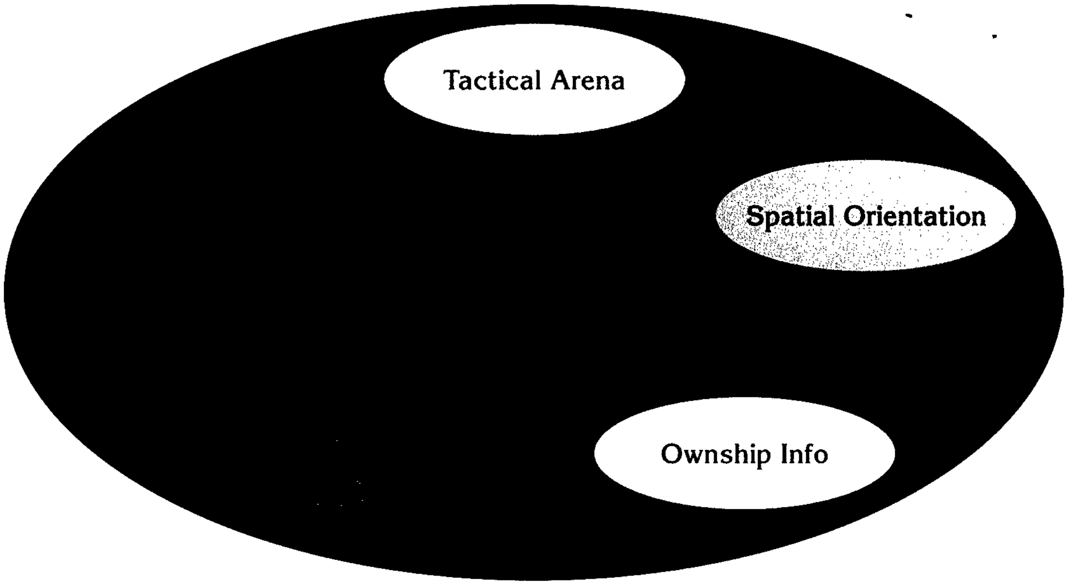

Figure 1. An illustration of the relationship between spatial orientation and situation awareness. In this scheme, spatial orientation is a subset of situation awareness. (Adapted from Previc et al., 1995).

example, a pilot maintains adequate terrain clearance for a particular set of geographical coordinates that differ from those the aircraft is actually flying over, the pilot may not be aware of impending mountains, power lines, etc. Also, CFIT accidents typically occur during only one particular type of SD (Type I), in which the pilot is unaware of his or her misjudgment of terrain clearance, whereas in many SD situations the pilot may be fighting to maintain control of the aircraft before impacting the ground (Types II and III SD).

The thing to remember is that SD can be masked by several other names. If we are ever to reduce the number of human-error related mishaps, we must understand the reasons these events occur and focus our attention and resources on the causes and countermeasures. SD, GD, LSA, and CFIT are all related to misperceptions of flight. It has only been within the last decade that researchers have been able to convince the flying community of the seriousness of all these insidious killers.■

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Advanced Display Technologies:
What Have We Lost?

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The "Holy Grail" for designers of information displays—particularly aircraft cockpit displays—is maintenance of situation awareness. Spatial disorientation is an element that militates against good situation awareness. Rapid advance in technology permits us now to deliver information to the human operator by almost any sensory mode, potentially in layers of complexity, but understanding of the impact of this on human performance lags. While the intention of designers of advanced displays is to reduce elements such as spatial disorientation and operator workload, it is not clear that this will necessarily be the outcome.

With conventional information displays the experienced operator can often part-process segments of an information array by recognizing patterns in the raw data being presented. This can be seen, for example, in the behavior of a nurse in a surgical recovery room who monitors the patient's vital signs, or a submarine sonar operator scanning for targets. Experienced operators can recognize patterns in arrays of raw data that indicate a "normal" state or a state that requires a response. This gives rise to a question about what has been lost in advanced information displays that use new and very different concepts and methods.

Workload: Reduction or Overload?

Head-up displays (HUDs) and helmet-mounted displays (HMDs) are capable of putting visual symbology in the line of sight of the operator, and advanced auditory displays can position a large array of different sounds virtually anywhere in space. In addition, techniques now enable voice communication between the operator and inanimate systems. There is quite a lot of experimental data on line-of-sight visual displays, a growing amount of data on spatial and other auditory displays, and some data are beginning to emerge on direct-voice recognition systems. However, we have no data yet on how all this works together. A clear possibility is that poorly configured information delivery systems will produce a result that is opposite of that which is intended. Rather than reducing the operator's workload, advanced information display systems have a potential to produce an overload of information. At present DSTO is a partner in a collaboration under a Memorandum of Understanding between the French and Australian governments to investigate display and control technologies in a simulated combat mission environment. The object of the collaboration is to understand the outcomes of addressing information to the different sensory modes and enabling inanimate onboard systems to respond to voice commands of the pilot. The objective of this is the evolution of some general principles for design and implementation of such systems in the next generation combat aircraft.

Data Fusion

The potential for loss of situation awareness may be further exacerbated by data fusion. In the examples above, the nurse has access to raw data in the form of heart, respiration rates, and so on, and the sonar operator has raw data in the form of sonar returns. Data fusion formats, on the other hand, are likely to enable the operator little or perhaps no access to raw data. A fused-data situation display showing an entity—say, a threat—may have difficulty attaching any indication of the "trustworthiness" to what it is indicating. We have conducted structured interviews with tactical operators, who reveal that they seek verification of information indicated by sensor signals in the nature and behavior of those signals over time. Fused-data formats are ill adapted to this. Even with the application of "smart" enhancements it is difficult to imagine a

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means by which such dimensions of information might be reconstituted in a display. For example, a ground-to-air threat indicated in the cockpit of a strike aircraft, received from an Airborne Early Warning and Control (AEW&C) platform, may in turn be received from another platform that is airborne, at sea, or on the ground. It may be that the source of the original signal is informative to the strike aircrew, but that this information is lost in the fusion. It is possible to imagine many other characteristics of raw data that potentially will be lost in fusion.

This problem is already recognized by operators pondering fused-data presentation systems. It is likely that data fusion technology will sometimes not permit reversion to raw data. The challenge is to devise means of restoring to fused-data displays information that can go some way towards compensating for the loss of information afforded by access to raw data.

Attentional Capture

Another clearly unwanted outcome of line-of-sight displays is their potential to act as an attentional "trap." The term "cognitive capture" has been used to describe this well-recognized and robust phenomenon, but we prefer the term "attentional capture" as it includes cases that are not adequately described as cognitive (Stuart, McAnally and Meehan, 2001a). Attentional capture is thought to be involved in some instances of spatial disorientation related to controlled-flight-into-terrain accidents. Pilots are trained to scan visually to maintain situation awareness and also because this can reduce attentional fixedness following a period of fixedness of gaze. However, whereas the pilot can look away from line-of-sight symbology that is presented in a head-up display (HUD), this is not possible with helmet-mounted display symbology—except in the case of symbology presented at a fixed location in virtual space. Certainly symbology can be deleted with a de-clutter function, but this is analogous to merely switching off distracting auditory communications; it can assist recovery from attentional capture, but may do nothing positive to support situation awareness.

We have shown in laboratory experiments that the way visual symbology is displayed can significantly influence response time to stimuli overlaid by the symbology (Stuart, McAnally, and Meehan, 2001b). This paradigm is an abstraction of the HUD/HMD situation. High-contrast overlaid symbology can impose a cost in response time. Experienced pilots customarily turn the brightness of the HUD up or down as appropriate so that symbology is comfortably visible in ambient conditions, indicating that they are already aware of this intuitively. The way symbology is written can also potentially affect human performance adversely. It has been shown that verisimilitude of HUD symbology with salient ground features will lead unalerted aircrew to fail to detect an important event that is clearly visible. Other aspects of symbology such as implied direction or other semantic content also present a potential for unintended and unwanted effects.

These matters should be of particular concern to aircrew in combat aircraft—both fast jets and rotorcraft—that operate close to terrain, and those involved in operations and training the aircrew to perform them. More research is required into the basic processes invoked by new display techniques that can result in effects the opposite of that which is intended. Identifiable perceptual and cognitive processes are involved, and research into these processes should also have a robust theoretical foundation.■

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Desdemona:
Advanced Disorientation Trainer

Dr. Willem Bles

Desdemona is a sophisticated demonstration, simulation and training facility specified by Toegepast Natuurwetenschappelijk Onderzoek (TNO) Human Factors and developed by AMST Systemtechnik (Austria). Desdemona is planned to be operational in 2003 at the TNO Human Factors facility in Soesterberg, the Netherlands, for basic and advanced disorientation training courses for the benefit of the Royal Netherlands Air Force (RNLAF).

At present all student aviators from the RNLAF follow basic spatial disorientation (SD) training at TNO Human Factors where they passively experience the limitations of their vestibular and visual sensory systems on the different research tools. The Desdemona concept was developed to extend that course to the flight environment with the man-in-the-loop, but still with the ability to demonstrate all vestibular and visual illusions as occur in flight without cheating.

Consequently, Desdemona Soesterberg is designed to offer the motion profiles required for the basic disorientation course such as unlimited rotation and prolonged > 1g motion profiles. This is accomplished by unrestricted rotation of a fully gimbaled cockpit (max yaw, pitch and roll angular accelerations 90°/s2) and by rotation of the track, which allows centrifugation up to 3g if the cockpit is in an outer position (see Figure 1). Realistic environment with state-of-the-art visuals and aircraft specific instruments is available in the cockpit, including night-vision. This, together with the vertical motion (the gimbaled cockpit may move 2m along a straight vertical guide) and the horizontal motion (the gimbaled cockpit and the vertical guide may move 8m over the horizontal track), both with maximal accelerations of 0.5g, allows for semi man-in-the-loop simulation in the refresher course.

Proper combination of the 6 degrees of freedom (DOF) makes Desdemona also a dynamic flight simulator. Desdemona may replicate the motion envelopes of a conventional Stewart platform and a gimbaled centrifuge. By the horizontal motion over the track, the Desdemona concept adds a sustainable G-load to the conventional Stewart platform motion, without the angular accelerations encountered in centrifuges during the G-onset.

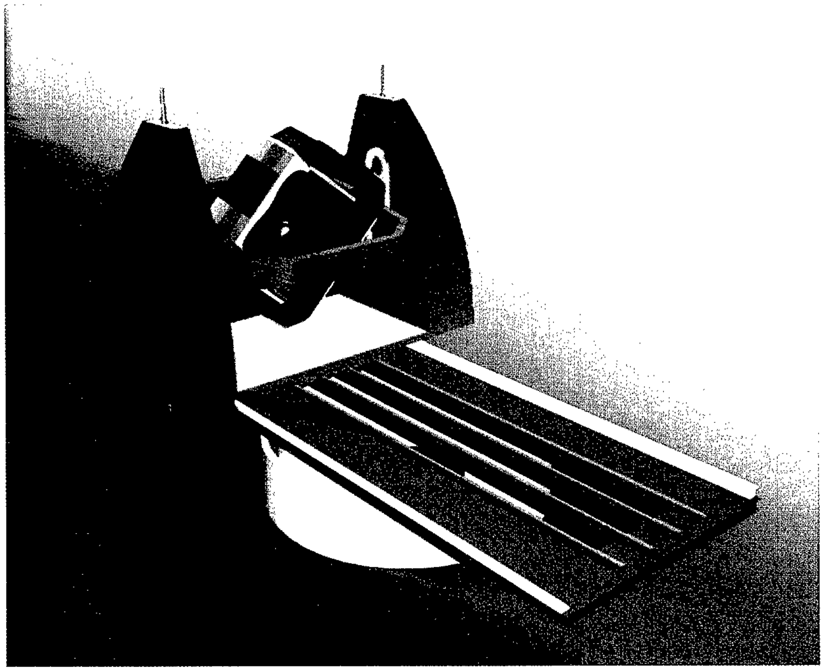

Figure 1. The Desdemona concept: Basic vestibular and visual disorienting illusions to be demonstrated with the pilot in control.

All these motions make Desdemona a valuable tool for research on the vestibular and cardiovascular consequences of (super) agile aircraft maneuvers. Desdemona is also an ideal research tool to determine to what extent the Desdemona concept can be used as a flight simulator for fighter aircraft, as a driving simulator, a helicopter simulator, etc. Desdemona should prove to be superior over standard hexapod motion platforms when sustained G-loading is required (for driving simulation: braking and accelerating, driving winding roads, making lane changes. For flight simulation training: take-off and landing, especially from a carrier, and unusual attitude recovery, highly maneuverable flight profiles, etc.).■

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