Spatial Disorientation Mitigation Through Training

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ABSTRACT

Spatial disorientation (SD) has been a leading cause of flight accidents since flight began. Mitigation of the threat of SD has been a concern of aviation professionals for almost as long. Over the century of powered flight SD has always been present though called by a variety of different names, and the attempted mitigation of its effects has taken many forms; technical such as flight instruments from the most basic panel to advanced projected flight symbology. Attempts to select aviators resistant to the effects of SD, efforts to 'condition' aviators to enable them to maintain their orientation and situational awareness, but the single effort that has been universal and ubiquitous is the training of aviators to either avoid SD in the first place or to be able to recognize SD and maintain safe control of the aircraft. This has met with varying levels of success and only recently has any scientific rigor come to this arena. Presented here is a history of efforts to mitigate SD and a summary of the objective scientific evidence to support these efforts.

Related Documents (RD)

A. NATO RTO TECHNICAL REPORT TR-HFM-118. Spatial Disorientation Training –Demonstration and Avoidance. Final Report of Task Group TG-039

B. Previc FH, Ercoline WR. Spatial Disorientation in Aviation. Vol 203, Progress in Astronautics and Aeronautics. 2004

C. NATO STANAG 3114 (Edition 9) Aeromedical Training of Flight Personnel

Introduction

This paper is a companion piece to the lecture of the same name as part of the North Atlantic Treaty Organization (NATO) Science and Technology Organization lecture series HFM-265 on "Mitigating Hazards to Rotary Wing Flight in Degraded Visual Environments". It is not designed as a comprehensive guide to the subject as many reviews have been published in the area, but as an illustrative guide to the area of spatial disorientation (SD) mitigation through training. If the reader wishes more wide-ranging and complete information they should refer in the first instance to two publications: RD A and B.

And if the reader wishes to find the current NATO regulation on SD training they can be found at RD C.

One of the major barriers to overcoming resistance to extra training (and cost) in aviation is the difficulty of proving efficacy. This can be attempted by showing validity; either face or content but the most difficult element has always been predictive or evidential. Does the change you make have a causal relationship with an outcome, ideally beneficial? This conundrum will be addressed later in the paper and the somewhat limited evidence of the benefits of SD mitigation training will be explored. This paper will largely be restricted to discussions of rotary wing (RW) aviation but will stray into broader definitions periodically.

History

Spatial Orientation (SO) is arguably the most fundamental of all behaviors that humans engage in and it involves a large number of different sensory and motor systems and brain regions. SD represents a failure to maintain SO, which in the flight environment all too frequently proves catastrophic.[1] Various assessments over the years have placed SD as the cause of between 25 and 35% of serious accidents and 25 to 50% of aviation fatalities.[2,3,4] This toll has been largely consistent over time despite numerous efforts to solve the problem. The most commonly accepted definition of SD is that of Benson: "SD occurs when a pilot fails to sense correctly the position, motion or attitude of himself or his aircraft within the fixed coordinate system provided by the surface of the earth and the gravitational vertical." This definition clearly excludes getting lost but would include impact with an object on the ground that the pilot knew to be there.

What is now defined as SD was not always so, in the early days of aviation and even into the 70s the terms aviator's vertigo and pilot vertigo were in common usage. Another term, that gained currency during WWII, was 'Loss of Situational Awareness' (LSA), this regained momentum during the 80s and became something of a research focus. The definition was broader and included not knowing where you were, thus if you were suffering from SD you also had LSA but not necessarily the converse. The recognition of the potential hazards of SD goes back almost to the beginning of aviation and some of the earliest efforts to combat the problem, in the absence of significant technical advances, were made in the area of training.

Early Training

The early understanding of the vestibular system and illusions arising from it in motion were described by the physicist Ernst Mach in the late 19th century[5], he experimented with the fluid dynamics of the system and was the first to use equipment such as a rotating chair and a crude centrifuge. He also experimented with visual-vestibular interactions using a rotating striped drum to surround the subject, thereby demonstrating among other things the vection illusion. Early training therefore was based on stimulation of the vestibular system to produce rotational illusions and the mainstay of this process was the Barany chair. Robert Barany was a physiologist who was awarded a Nobel Prize in 1913 and who designed a low friction rotating chair that is still one of the mainstays of SD training to this day. In the 1920s a basic flight instrument package called the Ocker Box was added to train pilots in 'blind flight' and devices gradually increased in their complexity. Over the next 70 years machines with a wide field of view, collimated visual systems, cockpit motion in pitch, roll and yaw, reprogrammable glass cockpits and pilot-in-the-loop controls were all used in SD training.

The early devices were used largely as demonstrators, and measurement of effectiveness was rarely attempted, largely because these devices never had the capabilities of a flight simulator. This changed with the advent the Gyrolab 2000 around 1993, the device, developed by the USAF as the Advanced Spatial Disorientation Trainer, that presented illusions and allowed the pilot to attempt to fly out of them. Basic SD profiles, type I and II, were developed and tested in 1995 and the results supported this type of training[6].

Concurrently with the use of increasingly complex SD training devices the concept of ground based physiological training of aircrew was gaining ground. The syllabi gradually came to include the basics of the inter-relationship between visual, vestibular kinaesthetic systems and their limitations in the flight environment. Ground SD training is now an integral part of every professional pilot's initial and continuation teaching although its penetration into general aviation is still somewhat limited.

Academic SD Training

It is generally recognized that SD training should be part of the flight training as a whole and needs to be incorporated in the training syllabus. This concerns not only ab-initio training, but also continuation and recurrent training. Since the objective of SD training during a pilot's career will change with the development of the pilot's capabilities, type-specific SD-provocative aircraft peculiarities, and SD-provocative peculiarities of the operating theater (like brown-out when operating in the desert), SD training is a recurrent issue of vital importance in the training syllabus.

The training may be divided basically in three parts. The first part comprises the Academic Instruction about SD, i.e. the trainee has to become aware of the human motion perception process, its working limits, and the resulting possibility of the occurrence of SD. The second part is the demonstration of the

SD illusions to illustrate the theory and to enhance the awareness of the SD risks. These demonstrations may be performed with relatively simple ground-based devices or with in-flight demonstrations. The third part comprises the SD training, i.e. the (student) pilot learns how to avoid SD and how to handle SD when it is encountered. This may be accomplished with in-flight SD training and partly with advanced ground-based SD devices with a flight simulation capability and with full flight simulators. Night Vision Devices have also some SD provoking peculiarities. These aspects will be dealt with below.

One of the major problems encountered with ground-based SD devices is the motion cueing. Various vestibular and visual illusions may be demonstrated in an open loop mode. In closed loop control this requires special effect toolboxes with the pilot following a well-defined flight path. Recovery from SD under these conditions with a realistic motion percept and realistic control handling requires very sophisticated motion cueing algorithms and is – despite the multi-degrees of freedom (DoF) motion platforms – so far only possible for a limited number of SD illusions.

From the accident statistics we know that Type II (recognised) SD accidents do occur, but that Type I (unrecognized) accidents are more common. Apparently the pilots in those accidents aborted from their primary flying task for some reason such as distraction. Under those circumstances the human equilibrium system by itself is unable to sense the aircraft motion profiles correctly, leading to a gradual deviation of the intended flight path without the pilot noticing this, and finally to the accident. Practically all pilots admit that they have experienced SD in flight, so fortunately enough, in many occasions the pilots will become aware of their disorientation (transfer from Type I into Type II), which may often lead to restoring aircraft control[7]. The emphasis of demonstration and training should be on the familiarization with visual and vestibular illusions as may occur under flying conditions, on understanding the basic mechanisms involved and on the training of countermeasures for the prevention of SD and for recovery from SD once encountered. In fact, they should be made aware of how easily things may go wrong once the instrument cross-check is neglected.

In the SD demonstrations in many cases stressors are used (for instance anxiety stressors by introducing malfunctioning navigation equipment or poor weather conditions) to distract the pilot from his flying task leading to subsequent disorientation. This is useless for the demonstration of the basic vestibular and visual mechanisms, but is helpful if not necessary for demonstrating the in-flight illusions in a simulator under man-in-the-loop conditions.

Academic Instruction

The main cause of disorientation in flight is that the flight environment is not one that man evolved to operate in, the lack of a consistent gravitational vertical and a horizontal surface upon which to orientate prevents the human vestibular and kinesthetic receptors providing correct motion and attitude information. The most common vestibular ‘problems’ while operating outside the ‘normal’ motion envelope are the inability to signal constant velocity rotation and the affection of the perceived direction of the gravitational vertical by sustained linear accelerations. The first typically leads to somatogyral, the second to somatogravic illusions in the absence of reliable visual information (in clouds, at night). Together with visual illusions this explains the majority of the in-flight SD illusions perceived by fixed wing pilots. In the academic instruction not only the mechanism of orientation and disorientation should be dealt with, information on how to prevent disorientation and how to manage recognized disorientation is equally, perhaps even more important. Although one may argue that emphasis should be laid on the prevention and management of disorientation because of lack of training hours, it is also obvious that once the mechanism is understood, prevention and management are more logical, and therefore easier to remember and to apply.

For a detailed ground syllabus please refer to Annex A, re-printed from RD A.

SD Demonstration

The aim of this part of the course is that student pilots learn and experience the limitations of their visual and vestibular sensory systems and understand that these limitations are the underlying cause of in-flight SD illusions. Experiencing these visual and vestibular illusions raises the students’ interest in SD and determines their mind setting, especially if combined with some stories on SD incidents or accidents. In fact, in this part of the course the main building blocks are provided necessary to explain the various in-flight illusions. In the concurrent explanation the instructor should construct the bridge toward the typical in-flight illusions leading to SD, which are demonstrated mostly in the same session.

Under low visibility conditions and without functioning flight instruments sustained linear and angular accelerations necessarily result in SD. This will happen not only in special flight profiles, but also in standard flight profiles, such as a take-off or a 180 degree turn. These primarily *vestibular* effects are easily demonstrated in a ground-based facility and the underlying physiological principles are also easily explained. For these demonstrations simple, but man-rated rotation devices are required with concentric and eccentric rotation, such as the DISO and Gyrolab® devices. After the demonstrations it is very important that students observe their own reactions (“from the inside out”) and compare these with what they see and hear from their colleagues as a bystander ("from the outside in"). This form of basic training is useful for trainee pilots early in their courses but is of less utility in more seasoned aviators, for these pilots a more immersive operationally relevant experience is of more value.

For demonstration of in-flight illusions on the ground, a whole range of devices is available. On the one hand there are special SD training devices of different levels of complexity (categorization below); on the other hand there are full flight simulators, centrifuges and mission trainers, which are used to train SD related aspects in between their normal service. No device is suitable to demonstrate all illusions: For instance, Mission Trainers are primarily fixed base trainers with sometimes excellent opportunities to train the SD aspects of Night Vision Devices, but they are not suitable for demonstrating typical vestibular illusions. Similarly, full flight simulators may significantly contribute to SD training and should be used accordingly (see below), but they fall short in simulating SD if sustained accelerations are involved.

Table 1. Categorization of SD Devices According to AIR STD 61/117/14

Device Category 1:	A device capable of yaw rotation only (e.g. the Barany Chair)
Device Category 2:	A device capable of yaw rotation and limited roll, pitch and/or heave that has full/partial close looped subject control.
Device Category 3:	Devices with a 4 DoF motion base (pitch, roll, yaw, and planetary), which provides 2 – 3 Gz sustained acceleration.
Device Category 4:	Centrifuge devices having 6 DoFs such as roll, pitch, yaw, heave, surge, and sway with 2 – 3 G capability.

The latter device category in the table above is currently limited to two devices worldwide, the Desdemona device in the Netherlands and the recently opened Kraken device at the USAF research laboratory at Wright-Patterson AFB. They were both intended purely for research but the Dutch device is now being used for SD training of fast jet pilots.

The use of 6 Degree of Freedom (6DoF) flight simulators in SD training has been mooted for at least the last 20 years and despite not being designed as specific SD training platforms they have been shown to have significant utility in the area.

At the US Army Aeromedical Research Laboratory (USAARL), flight scenarios were developed in the NUH-60 flight simulator[9,10]. Actual SD accident summaries from the US Army Combat Readiness Center (USACRC) were reviewed and those that could reasonably be replicated in a visual simulator were selected. The research data collected following comprehensive demonstrations indicated a very favorable response to this method of training. The result was that aviators receiving SD scenario training increased their situational awareness of the conditions and events that lead to SD. In addition, the scenarios provided training to assist aviators in **overcoming** SD once it was encountered. Additional benefits from this method of training were found to be the reinforcement of crew resource management elements and the development of decision-making, risk assessment, and judgment skills. A similar study was conducted at the Royal Air Force Centre of Aviation Medicine (RAF CAM) that showed a positive correlation between scenario-based SD instruction and trained pilot capabilities in dealing with flight conditions pre-disposing to SD[RD A].

To summarize, the flight simulator presents an excellent opportunity to capitalize on this training device to enhance awareness and coping strategies for helicopter operations. Aviators receiving SD scenario training increased their situational awareness of the conditions and events that lead to SD. In addition, the scenarios provided training to assist aviators in overcoming SD once it was encountered. Additional benefits from this method of training were found to be the reinforcement of crew resource management elements and the development of decision-making, risk assessment, and judgement skills. It is vital that the scenarios are not viewed in isolation, but instead embedded in a complete training package that is part of the larger training process.

In-Flight SD Training

This section concerns the demonstration of the limitations of the orientation senses in flight, especially those of the vestibular system and the ‘seat-of-the-pants’. Demonstrating the limitations of the human equilibrium system in the aviation environment has a distinct advantage above the demonstration in ground-based devices, since it concerns the real aircraft motion. This makes it also more convincing for experienced pilots for the refresher courses, because it is the environment in which they operate. Assessment of the rotary-wing version of this SD demonstration in the British and American Armies has shown that aircrew’s “awareness” of the limitations of the orientation senses is greatly enhanced. It also saves lives and money: The British Army Air Corps experienced a 75% reduction in the SD accident rate, since instituting this enhanced awareness training in helicopters[11].

The RAF designed a SD demonstration in Fixed Wing (FW) aircraft for high performance flight profiles in the Hawk[RD B]. The demonstration could be adapted for other high performance FW aircraft, whereas application of the principles for SD demonstrations in low performance or multi-engine aircraft is feasible, although some modifications may be required to get the desired effect. The power of the demonstrations is that they consist of real flight profiles. The combination of somatogravic and somatogyral illusions convincingly illustrates how inaccurately human senses predict orientation relative to the earth's surface. However, high-performance FW aircraft have a maximum of two seats. In contrast to the Rotary Wing (RW) SD demonstration, this FW SD demonstration must therefore be performed "one-to-one". This has consequences for the student: They can only play the role of subject, not of observer. As subject they realize their disorientation at the moment they open their eyes, but they have no cue as to how they reached that position. They therefore don't get an understanding for the development of the SD over time, something the observers in the RW SD demonstration learn by comparing the flight profile and the verbal report of the subject.

RW specific SD Training Challenges

SD is a prevalent and persistent hazard for rotary crews. UK surveys within the recent past have indicated that it is a causal or contributory factor in about one third of serious military RW accidents[12,13] with rates undiminished over the recent past. SD accidents also feature higher fatality rates when compared to non-SD accidents (44% vs. 19%)[12]. The need to operate helicopters within ever more challenging environments (e.g. DVE, low level, hostile) makes SD the single greatest physiological challenge for RW crews. Notably, Controlled Flight into Terrain (CFIT), a frequent outcome for SD, is a top level risk to life for military aviation commanders across the world, underlining the importance of managing the SD hazard.

The primary cause of RW SD accidents is more often inattention (36%) or visual mis-information (33%); vestibular mis-information only accounts for 11% of accidents[14] and these are rarely the traditionally taught somatogravic, somatogyral or coriolis illusion; more commonly they are sub-threshold accelerations resulting in unrecognised drift or attitude change. The same study reported that 83% of RW SD <u>accidents</u> feature Type 1 (unrecognised) SD; a second study reviewing RW SD <u>incidents</u> showed 59% of SD incidents were unrecognised. The increasing requirement to fly systems intensive aircraft in challenging operational environments aggravates the problem. It is therefore desirable to focus limited SD training resources toward the areas of highest risk i.e. **recognising** incipient SD at times of **high workload** and / or **deceptive visual cues**.

As has been detailed above two principal modalities for practical demonstration are used in SD training; a category 2 training device & in-flight demonstration; immersive synthetic scenario training, once validated, is added as a desirable third. Characteristics of each are listed in Table 1. An alternative approach is required if RW aviation is to significantly improve aircrew awareness and reduce future SD accidents in RW operations; specifically:

a. Focus on the primary causes of inattention and visual mis-information. There is currently too great an emphasis on traditional vestibular illusions which have limited relevance to RW operations.

b. Use contextual and interactive learning where aircrew are able to make decisions and fly themselves into a relevant and risky situation. This should incorporate workload, CRM, relevant environments and be conducted on an equivalent training platform.

Table 2. SD Demonstration methodologies

SD Training Type	Learning Objectives	Merits	Shortfalls
Disorientation trainer (DISO)	Demonstrate relevant visual and vestibular illusions to reinforce academic teachings	Wide range of established and compelling visual challenges Interactive (for trained cohort) SQEP delivery Safe	Ltd focus on inattention Vestibular illusions, whilst compelling, have FW bias No CRM Ltd field of view and fidelity Generic cockpit Ltd supportive evidence[11,15]

SD Training Type	Learning Objectives	Merits	Shortfalls
In-flight demonstration	Demonstrate the limitations of the orientation systems within a contextual RW environment	Compelling demonstration using representative RW motion & acceleration SQEP delivery Distributed training Good supportive evidence[11,16,17]	Vestibular bias. Ltd focus on inattention and visual causes. No CRM Demonstration only Aircraft availability
Immersive synthetic scenarios	Improve recognition of SD through interactive training within a representative role environment	Addresses the primary causes of RW SD (inattention and visual mis-information) Interactive, immersive and contextual - task and type specific NVG compatible Safe Distributed training Some supportive evidence[18]	Ltd relevance for ab-initio pilots; no scope for rearcrew Simulator availability Potential loss of SQEP delivery

No single practical demonstrator offers a complete package for improving aircrew recognition and avoidance of SD. A layered approach which reflects aircrew experience, aircrew role and unit training capabilities is recommended for a more effective, targeted package. It is also debatable whether the minimum provision of SD training once every 5 years is frequent enough, especially in the early years of a pilot’s career when SD accidents are more frequent. The following layered SD training pathway is recommended:

Table 3. Recommended SD training timetable

Ab-initio students	**Training Phase**	**SD Training**
Year 1	Basic RW Trg	DISO
Year 2	Advanced RW Trg	In-flight demonstration
Post-graduate aircrew		
Every 2 years	EQ or Sqn Refresher Trg	Synthetic scenario training
Every 5 years	Avn Med Refresher	DISO / in-flight demonstration

References

1. Previc FH, Ercoline WR. Spatial Disorientation in Aviation. Vol 203, Progress in Astronautics and Aeronautics. 2004.
2. Braithwaite MG, Groh SL, Alvarez EA . Spatial disorientation in U.S. Army helicopter accidents: an update on the 1987-92 survey to include 1993-95 . Fort Rucker, AL : U.S. Army Aeromedical Research Laboratory ; 1997 . Report No. 97-13.
3. Curry IP, McGhee JS . Spatial disorientation as a cause of mishaps in combat helicopter operations [abstract] . Aviat Space Environ Med 2007 ; 78 : 307.
4. Gibb R, Ercoline B, Scharff L . Spatial disorientation: decades of pilot fatalities . Aviat Space Environ Med 2011 ; 82 : 717 – 24.
5. Henn V, Young LR. Ernst Mach on the Vestibular Organ 100 Years Ago. ORL. Vol 37, 1975, pp 138-148
6. Yauch d, Ercoline WR, Previc FH and Holoviak SJ. The Advanced Spatial Disorientation Demonstrator: Component Profile and Training Evaluation. AGARD CP-588: *Selection and Training Advances in Aviation*, AGARD, 1996, pp 28-1 – 28-5
7. Benson AJ (1999). Spatial disorientation – General Aspects. In: Aviation Medicine, 3rd edition, edited by Ernsting J, Nicholson AN and Rainford DJ. Pages 419-436. Butterworth-Heinemann, Oxford, England, United Kingdom.
8. Estrada A, Braithwaite MG, Gilreath SR, Johnson PA and Manning JC (1998). Spatial Disorientation
9. Awareness Training Scenarios for U.S. Army Aviators in Visual Flight Simulators. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 98-17.
10. Estrada A, Adam GE and Leduc PA (2001). Use of Simulator Spatial Disorientation Awareness Training Scenarios by the U.S. Army and National Guard. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2001-08.
11. Braithwaite M (1997). The British Army Air Corps in-flight spatial disorientation demonstration sortie. Aviation Space Environ Med; 68:342-5.
12. Bushby A, Holmes SR, McGowan A, Bunting A, Panchal R, Stott J. An Assessment of the Influence of Spatial Disorientation upon Military Aircraft Accidents from 1983 to 2002. QinetiQ/05/00474. March 2005.
13. Adams MS, Curry IP, Gaydos SJ. British Army Air Corps accidents, 1991–2010: a review of contrasting decades. Aviat Space Environ Med 2014; 85:852–6.
14. Holmes R, Stott J, Arrowsmith C, Bushby A. An Alternative Approach To Surveying For Spatial Disorientation Incidents In UK Rotary-Wing Military Aircraft. QinetiQ Technical Report 06/0611. March 2006
15. Spatial Disorientation Training. Institute of Aerospace Medicine, Indian Air Force, Bangalore. Ind J Aerospace Med 50(1), 2008
16. Braithwaite et al. An evaluation of the British Army spatial disorientation sortie in US Army aviation. Aviation Space Environ Med 1998; 69:727-732.
17. Durnford SJ. Disorientation and flight safety – a survey of UK Army Aircrew. Neuilly-sur-Seine:

AGARD, 1992; conference Proceedings 532.
18. Grimshaw T, Stott R. Conducting Refresher Spatial Disorientation Training in Rotary Wing Flight Simulators; a trial at RAF Benson. QinetiQ/10/00329/1.0. Feb 2010.