NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO TECHNICAL REPORT **TR-HFM-118**

Spatial Disorientation Training – Demonstration and Avoidance

(Entraînement à la désorientation spatiale – Démonstration et réponse)

Final Report of Task Group TG-039.

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Spatial Disorientation Training – Demonstration and Avoidance

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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List of Acronyms

3-D	Three dimensional
AB	After Burner
ACAS	Aircraft Collision Avoidance System
ACM	Air Combat Manoeuvres
ADI	Attitude Display Indicator
AF	Air Force
AFB	Air Force Base
AFCS	Automatic Flight Control System
AFRL	Air Force Research Laboratory
AGARD	Advisory Group for Aerospace Research and Development
AGL	Above Ground Level
AI	Aircrew Instructor
AI	Attitude Indicator
AIAA	American Institute of Aeronautics and Astronautics
AMTI	AeroMedical Training Institute
AOB	Angle of Bank
AP	Aerospace Physiology
API	Aviation Pre-flight Indoctrination
APTO	Aviation Physiology Training Officer
ASAR	Arc Segment Attitude Reference symbology (similar to NDFR)
ASCC	Air Standardization Coordinating Committee
ATC	Air Traffic Control
AVMED	Aviation MEDicine
Avn	Aviation
CA	Consultant Advisor
CAVOK	Cloud and Visibility OK
CF	Canadian Forces
CFIT	Controlled Flight into Terrain
CML	*Centrum voor Mens en Luchtvaart*, Centre for Man and Aviation, RNLAF
CRM	Cockpit Resource Management / Crew Resource Management
CRT	Cathode Ray Tube
CTP	Course Training Plan
CTS	Course Training Standard
DDI	Digital Display Indicator
DESDEMONA	DESoriëntatie DEMONstrator Amst (advanced SD trainer by AMST)
DFS	Dynamic Flight Simulator
DISO	DISOrientation trainer (SD trainer DISO Airfox by AMST)
DoF	Degrees of Freedom
DOT	DesOrientierungs Trainer
EC	Enabling Check
EO	Enabling Objective
Fatt	Fighter Attack
FFS	Full Flight Simulator
FLIR	Forward-Looking InfraRed

FOV	Field of View
FS	Flight Surgeon
FTD	Flight Training Device
FW	Fixed Wing
GAF	German Air Force
GAFIAM	German Air Force Institute of Aviation Medicine
GCAS	Ground Collision Avoidance System
GPWS	Ground Proximity Warning System
Gyro IPT	Gyro Integrated Physiological Trainer (by ETC)
HCAM	Hellenic Centre for Aviation Medicine
HDG	Heading
HEA	Human Effectiveness Aircrew Training Division
HITS	Highway-in-the-Sky
HMD	Helmet Mounted Display
HMS	Helmet Mounted System
HP	Handling Pilot
HUD	Head Up Display
IFC	Instrument Flying Conditions
IFR	Instrument Flight Rules
IHADSS	Integrated Helmet And Display Sighting System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IP	Instructor Pilot
IR	InfraRed
ITAF	ITalian Air Force
JHC	Joint Helicopter Command
LED	Light Emitting Diode
LS	Landing Site
LSA	Loss of Situational Awareness
MD	Medical Doctor
MFD	Multi Function Display
MMR	Multi-Mode Radar
MSDD	Multi-Station Disorientation Demonstrator
NAMRL	Naval Aerospace Medical Research Laboratory
NASTP	Naval Aviation Survival Training Program
NATO	North Atlantic Treaty Organisation
NDFR	Non-Distributed Flight Reference symbology (similar to ASAR)
NHP	Non-Handling Pilot
NM	Nautical Miles
NOE	Nap of the Earth
NOMI	Naval Operational Medical Institute
NVD	Night Vision Device
NVG	Night Vision Goggle
OTW	Out-the-Window (visuals)
OVC	Overcast

PAR	Precision Approach Radar
PO	Performance Objective
PWR	Power
QFI	Qualified Flight Instructor
RAAF	Royal Australian Air Force
RADALT	Radar Altimeter
RAeS	Royal Aeronautical Society
RAF	United Kingdom Royal Air Force
RAF CAM	RAF Centre of Aviation Medicine
RFA	Remote Field Area
RNLAF	Royal Netherlands Air Force
RT	Radio Transmission
RTB	Return to Base
RTO	Research & Technology Organisation
RW	Rotary Wing
SA	Situational Awareness
SAM	Specialist in Aviation Medicine
SD	Spatial Disorientation
SID	Standard Instrument Departure
SORD	Spatial Orientation Retention Device
SP	Student Pilot
STANAG	Standardization Agreement
STD	Standard
SUPT	Specialized Undergraduate Pilot Training
TADS	Target Acquisition and Designation System
TCAS	Traffic-alert and Collision-Avoidance System
TG	Task Group
TNO	*Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek*, Netherlands Organisation for Applied Scientific Research
TOR	Terms of Reference
TSAS	Tactile Situation Awareness System
TTTD	TNO Tactile Torso Display
UA	Unusual Attitude
UAV	Unmanned Air Vehicle
UK	United Kingdom
UNT	Undergraduate Navigation Training
US	United States
USAARL	US Army Aeromedical Research Laboratory
USAF	United States Air Force
VMC	Visual Meteorological Conditions
WP	Working Party

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[1] The authors dedicate this report to Curtis Spenny, who enjoyed working on this report. He was unable to complete his contribution because of his untimely death.

Spatial Disorientation Training – Demonstration and Avoidance

(RTO-TR-HFM-118)

Executive Summary

The Problem

Spatial Disorientation (SD), the phenomenon that the pilot is unaware of the real orientation of the aircraft with respect to the earth, is still a major factor in aircraft accidents. This is demonstrated by a review of recent trends in several armed forces (Chapter 1). The analysis also shows that the type of SD accidents depends upon the operational environment (e.g. Brownout). Training (student) pilots about the causes and consequences of SD is common practice in most armed forces (Chapter 2). However, there are few standardized training procedures and demonstrators. Since there is much dispute about how training should be implemented, and since training devices vary from small to large, from pure demonstrators to full-flight simulators, an assessment is needed on existing and desired courses. Such an assessment, the goal of this report, should offer the NATO forces the information to structure the SD training efficiently, which should, in turn, reduce the number of SD accidents and incidents.

Scope of Available SD Training Options

Chapter 3 presents an overview of the available ground-based SD training approaches. It describes the contents of academic instruction, basic demonstrations of the underlying SD mechanisms, training on specific SD devices and finally SD training on full-flight simulators. In Chapter 4 an overview is presented on in-flight SD demonstration and training for rotary wing and fixed wing aircraft. In Chapter 5 SD avoidance training for night vision devices is described in detail.

Recommendations for Efficient Implementation of SD Countermeasures Training

A number of issues are discussed in Chapter 6 that are relevant for optimising the SD training: the target audience e.g. pilots, navigators, other aircrew, flight surgeons and aerospace physiologists; the different pedagogical techniques in SD lectures to the above groups; the timing of SD training (initial and refresher); the feasibility of having different phases of ground-based SD training in a pilot’s career; and finally, who should be a trainer. Chapter 6 also proposes which likely SD illusions, sensory conflicts or traps should be considered essential or desirable for each phase of training for both rotary wing and fixed wing aircrew. A differentiation is made for SD illusions that are more suitable for ground-based as opposed to in-flight training. Further recommendations include guidelines for formal evaluation of the pilot’s knowledge on SD post-training, general and practical advice on how to enhance SD awareness in aircrew and advice on how flight surgeons and aerospace physiologists might continue their interest in spatial orientation. For this purpose a handout on SD is considered useful for aircrew. In Chapter 8 an example of such a handout is presented. Since the quality of SD training depends primarily on the instructor, recommendations are made on minimum instructor qualifications for SD training as well as general guidelines to develop optimal strategies at different stages of the training program (Chapter 7).

With the contents of this report it is possible to implement an efficient SD training program in accordance with STANAG 3114 Edition 8, and to add special SD training courses for specific operational flight environments.

Entraînement à la désorientation spatiale – Démonstration et réponse

(RTO-TR-HFM-118)

Synthèse

Le problème

Le phénomène de Désorientation Spatiale (SD), le pilote en vol n'arrive plus à s'orienter par rapport au sol, est encore un facteur majeur des accidents d'avions. Une étude des problèmes actuels dans différentes forces armées le démontre (Chapitre 1). L'analyse montre aussi que les types d'accidents SD dépendent de l'environnement opérationnel (ex. : éclairage réduit). L'entraînement des (élèves) pilotes sur les raisons et les conséquences de la SD est couramment pratiqué dans la plupart des forces armées (Chapitre 2). Cependant, il existe peu de procédures d'entraînement normalisées et d'appareils de démonstration. Les nombreux conflits sur la manière d'implanter la formation, les dispositifs de tailles très différentes allant des démonstrateurs à des simulateurs ‹ full-flight ›, rendent nécessaires une estimation sur les cours existants et escomptés. Cette évaluation qui est la cible de ce rapport offrirait aux forces de l'OTAN les informations pour structurer efficacement la formation SD, ce qui devrait réduire le nombre d'accidents et d'incidents SD.

Vue d'ensemble des options disponibles en formation SD

Le chapitre 3 présente une vue d'ensemble des approches au sol de formation SD disponibles. Il décrit le contenu de l'instruction scolaire, les démonstrations de base des mécanismes sous-jacents SD, l'entraînement sur les dispositifs SD spécifiques et enfin la formation SD sur les simulateurs ‹ full-flight ›. Le chapitre 4 présente une vue d'ensemble de la démonstration SD en vol et de la formation sur les voilures tournantes et les voilures fixes. Le chapitre 5 décrit l'entraînement anti SD sur les dispositifs de vision nocturne.

Recommandations : implantation efficace de la formation des contre-mesures SD

Un certain nombre de questions pertinentes sur l'optimisation de la formation SD est abordé au chapitre 6 : les personnels concernés, par exemple les pilotes, les navigateurs, les autres membres d'équipage, les médecins aéronautiques, les physiologistes de l'industrie aérospatiale ; les différentes techniques pédagogiques pour les cours SD des personnels ci-dessus ; les horaires d'entraînement SD (formation initiale et recyclage) ; la possibilité d'avoir différentes phases d'entraînement au sol dans une carrière de pilote et enfin le formateur idéal. Le chapitre 6 propose aussi un choix des illusions SD, des conflits sensoriels ou des pièges essentiels ou souhaitables dans chaque phase de formation pour les équipages des voilures tournantes et des voilures fixes. Une différenciation est faite entre les illusions SD pour la formation au sol et celles pour la formation en vol. Des recommandations supplémentaires comprennent des directives d'évaluation formalisées des connaissances des pilotes après leur formation SD, des conseils généraux et pratiques sur l'amélioration de la prise en compte SD des équipages et des conseils pour continuer à intéresser les médecins aéronautiques et les physiologistes de l'industrie aérospatiale à l'orientation dans l'espace. A cette intention, une notice aux équipages sur le SD serait utile. Un exemplaire de cette notice est présenté dans le chapitre 8. La qualité de la formation SD dépendant principalement de l'instructeur, des recommandations sont données sur les qualifications minimums pour être instructeur et des directives générales sur les stratégies optimales à appliquer aux différentes étapes du programme de formation (Chapitre 7).

Il est possible grâce à ce rapport d'implanter un programme d'entraînement SD efficace conformément au STANAG 3114 Edition 8 et d'ajouter des cours de formation SD sur l'environnement spécifique des vols opérationnels.

Chapter 1 – INTRODUCTION

1.1 THE SPATIAL DISORIENTATION PROBLEM

Spatial Disorientation (SD) is a term used to describe a variety of incidents occurring in flight where the pilot fails to sense correctly the position, motion, or attitude of the aircraft or of himself within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical [1]. In addition, errors in perception by the pilot of his position, motion, or attitude with respect to his aircraft, or of his own aircraft relative to other aircraft, can also be embraced within a broader definition of spatial orientation in flight [2]. This broader definition relates to those cases where the other aircraft is actually used as a visual spatial reference point. Since the early years of flying about one century ago until now, SD has caused many flying accidents. For instance, over the period 1990 – 2005 the SD crashes in the USAF amounted to 11% of all crashes [3]. From the RAF and USAF SD mishaps about 80% are Type I, i.e. unrecognized spatial disorientation[1]. There is no specific training for countermeasures to Type I except more vigilance (crosscheck discipline) or reducing cockpit workload. And of course pilots should be made aware of this sort of SD accidents by demonstration of the involved mechanisms. Many of these mishaps ended up in Controlled Flight into Terrain (CFIT) probably because the pilot was focused on something other than flying the aircraft (channelized attention on map, changing radio frequency, caution light, etc.) and the aircraft has imperceptibly overbanked or lost altitude. The other 20% of the SD mishaps involve recognized SD (Type II), where pilots know they are disoriented, but cannot equate the conflict between instrument readings and perceived motion and/or attitude. It is SD training that can help with this part of the problem.

At the RTO Human Factors and Medicine Conference 'Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures' [4], it became clear that demonstrating and training (student) pilots about the causes and consequences of SD is common practice in most armed forces. However, training procedures are different, and so are the trainers/demonstrators. In view of interoperability it would be desirable to request at least a minimum level of aviator experience in this respect. Because of the considerable costs associated with SD flight accidents, this should be not a waste of money [5].

1.1.1 Recent Accident Statistics and Operational Implications

Mishap statistics over the second half of the 20th century show that the percentage of accidents in which SD was involved gradually increased. Statistics also showed that the percentage of fatalities in SD accidents was much higher [5]. They also stress the formidable threat to efficient and effective combat resource management.

1.1.1.1 Present Trends in the US and Canada

Recent accidents in the US Air Force, Navy, and Army show trends. From 1993 – 2002, the USAF lost 25 Fighter Attack aircraft and 19 lives to Class A SD accidents. This equates to a rate of 0.36 SD accidents per 100 000 flying hours or 13.2% of all Class A accidents. The accident rate for 2001 – 02 was below previous rates, although this may be early to predict a trend. Some of these mishaps in the period 1992 – 2003 have been attributed to Night Vision Goggle (NVG) use.

Unmanned Air Vehicles (UAVs) are being used more and more by the services. In 2004, the USAF lost 4 UAVs due to errors attributed to the operator. These are classified as Class A mishaps due to the cost of

[1] Air forces in other operating theaters may have different Type I / Type II ratios (Italian Air Force has a ratio of fifty-fifty): Operation in desert areas for instance involves many brownout incidents, typical examples of SD Type I/II.

the UAV. The USAF is developing UAV operator simulators and is evaluating techniques for improving height/position misperception in operators during landing of the UAVs.

In the Army, SD accident occurrence remains high. The proportion of Class A – C accidents from 1987 – 1995 which featured SD was measured at 30% [6]. From 2000 – 2005, using similar methodology but examining operational data only, the SD accident proportion was measured at 37% [7]. Losses due to SD under Operation Iraqi Freedom have been particularly extensive. There were 19 (Class A – C) accidents from 1 October 2003 to 7 September 2004, in which SD or Loss Of Situational awareness (LSA) appears to be implicated. Of these, 6 were Class A (>$1.000.000, destruction of aircraft, and/or fatality/permanent disability), 5 were Class B ($200.000 – $1.000.000, permanent partial disability, hospitalization of 5 or more), and 8 were Class C ($100.000 – $200.000, non-fatal injury, illness, or disability). Nine of the 19 accidents occurred in Iraq or Afghanistan (4 of the Class A's, 2 of the Class B's, and 3 of the Class C's). In five of the accidents, brownout appears to be a contributing factor. Brownout is a condition of reduced visibility for the pilot due to recirculating sand whilst manoeuvring at low altitude. Three appear to be inadvertent encounters with fog/rain, two to whiteout (whiteout is due to snow recirculation), eight to CFIT due to height/position misperception, and one occurred whilst ground taxiing.

In the US Navy during 2004, there were 30 mishaps resulting in the destruction of 27 aircraft and the loss of 19 lives. The Navy mishap rate has dropped over the past year. However, the Marine aviation mishap rate has doubled. Human error was causal in 83% of these mishaps.

In Canada flight statistics of the Canadian Forces (CF) have revealed the significance of SD as a contributing factor in aircraft accidents for the past 4 decades. From 1968 – 78, there were 12 accidents in which SD was listed as a cause factor, which resulted in the total loss of 10 aircraft and the lives of 8 aircrew [8]. More recently, two separate CF surveys and a CF study [9] have identified SD as the most detrimental of all listed aircraft and human factor issues in terms of its effects on flight safety and operational effectiveness. Fifty percent of the pilots in 1 Air Division Survey reported disorientation, 48% reported disorientation in the Fighter Group Survey. Forty-four percent reported problems with disorientation, of which 10% have experienced more than three incidents.

A retrospective study by Cheung et al. [10] confirmed that SD is a significant contributing factor in about 23% (14/62) of all category A accidents between 1982 – 1992. A Category A accident is defined as an event when the aircraft is destroyed, declared missing, or damaged beyond economical repair. Eleven of these accidents involved the loss of lives of 16 military and 8 civilian personnel. Disorientation is a factor not limited to flying trainees. It affects experienced pilots as well. SD is a flight safety hazard in all aircraft but is particularly hazardous in single seated aircraft and when combat pilots engage in activities that are known to cause and aggravate disorientation.

A recent survey from 48 high performance fixed wing single seat pilots yields the following: In 2 pilots the *elapsed time since last SD incident* (3 did not respond) was < 1 week, in 5 < 1 month, in 21 < 6 months, in 7 < 1 year, and in 10 > 1 year. The severity of the *most recent* SD incident (7 did not respond) was rated by 34 pilots as minor, by 6 as significant and by 1 as severe. The severity of *worst ever* SD incident (11 did not respond) was rated by 18 pilots as minor, by 17 as significant and by 2 as severe.

1.1.1.2 Present Trends in Europe

SD mishap statistics in some European countries show similar trends as the US statistics in terms of a significant percentage of accidents caused by SD/LSA with a relatively high percentage of fatalities. From some countries more details are shown below.

The Czech Military Air Force provided data on Class A mishaps over the period 1985 – 2005. Dividing that period in two periods (1985 – 1994, 1995 – 2005), data revealed a decrease of class A mishaps of

71 % in the second period compared to the first period (58 v. 17 accidents). The number of fatalities decreased with 61 % (44 v. 17). However, the percentage of mishaps attributed to Loss of Situational Awareness and SD (LSA/SD) rose to 88 % (32 v. 15), indicating that, although the total number of mishaps decreases, Human Factor errors like LSA/SD have a very significant influence on the remaining accidents. Analysis over the years 1991 – 2005 shows an average of 1.6 SD Class A mishaps per 100.000 flight hours. Spatial Disorientation was the major cause in 23% of the Class A mishaps in this period, and these SD mishaps accounted for 50% of all fatalities.

The Italian Air Force (ITAF) provided data on Class A mishaps over the period 1993 – 2004. From that survey it is shown that in 19% of the accidents SD was involved (8 out of 43 mishaps), whereas 33% of the fatalities occurred in the SD accidents (6 out of 18 fatalities). The number of SD class A mishaps per 100.000 hrs is 0.55. Therefore the ITAF started in 2001 a ground-based SD training program for all student pilots and an advanced SD avoidance training for all single seat fighter pilots. Recently in-flight SD demonstration was started for RW student pilots.

The Royal Netherlands Air Force (RNLAF) reported 48 Class A mishaps over the period 1980 – 2005. In eight of these mishaps (16.7%) SD was involved. Seven of these accidents (Six with F16s and one with a Bolkow helicopter) occurred in the period 1980 – 1995. Those accidents had a 100% fatality rate. For the F16 this meant a SD-related class A mishap rate of 1.6 per 100.000 flying hours over that period. In the period 1995 – 2005 only one class A mishap was classified as caused by SD. This was a helicopter accident and was due to brownout. For all aircraft the SD related Class A mishaps show a decrease from 1.0 per 100.000 flying hours over the period 1980 – 1995 to 0.3 over the period 1996 – 2005. The striking decrease of SD-related accidents of F16 aircraft might be due to changing operational theatres, lessons learned or to the SD training courses which started in the early nineties. The brownout accident showed the necessity to adapt the SD training course to the new operating theatres or to provide the pilot with better orientation information.

In France 4% of the Class A mishaps of the French Air Force over the years 2000 – 2004 has been attributed to SD (2 out of 45). The Class A mishap rate over these 4 years was 0.54 per 100.000 flying hours.

In Germany 5% of the Class A mishaps of the Bundeswehr over the years 1995 – 2006 have been attributed to SD (4 out of 82). From these mishaps 50% could be attributed to white-out and brown-out. The SD Class A mishap rate in Germany over these 10 years was 0.17 per 100.000 flying hours.

In Sweden the Swedish Air Force experienced 30 Class A mishaps during the period 1986 – 1995. The relative mishap frequency was 2.81 mishaps/100.000 flying hours. Seven mishaps had Loss of Situational Awareness (LSA) as the main factor. A further subdivision showed that SD was a possible cause factor in five of those mishaps (SD accident rate per 100.000 flying hours: 0.47). During 1996 – 2005 there were 12 Class A mishaps. The relative mishap frequency was 1.95 mishaps/100.000 flight hrs. Eight (!) mishaps had LSA as cause factor and of those, six mishaps had a SD cause factor or at least a clear visual component of SD (SD accident rate per 100.000 flying hours: 0.97).

In the UK a systematic survey of all categories 4 and 5 aircraft accidents over the period 1983 – 2002 was performed [11]. They found that the overall aircraft accident rate per 100.000 flying hours fell when the 1983 – 1992 period was compared with the 1993 – 2002 period (4.17 to 2.70 accidents per 100.000 hours, $p < 0.001$) and this was particularly evident for rotary wing (4.07 to 2.37 accidents per 100.000 hours, $p < 0.01$). The aircraft SD accident rate per 100.000 flying hours (i.e. aircraft accidents where SD was present in the handling pilot) was not significantly different between the two periods (see Table 1.1) and this was observed across all aircraft categories.

Table 1.1: Percentage of Accidents Featuring SD for the Two Analysis Periods

	1983 – 1992			1993 – 2002		
	SD accident rate (per 100.000 flying hrs)	**All cause accident rate (idem)**	**Percentage (%) of accidents featuring SD**	**SD accident rate**	**All cause accident rate**	**Percentage (%) of accidents featuring SD**
Fast Jet	1.70	7.02	24.2%	1.63	5.78	28.2%
Rotary Wing	0.99	4.07	24.3%	1.00	2.37	42.2%
All Aircraft	1.03	4.17	24.7%	0.88	2.70	33.0%

Both fast jet and rotary wing aircraft accident rates showed a decline over the period with no additional trend that might have been obscured by the ten-year period illustration. Aircraft SD accident rates remained at around the same level over the whole period, again with no obscured trend.

Across all aircraft categories, the percentage of aircraft accidents with fatalities was 2.2 fold higher in SD accidents compared with non-SD accidents (49.4% vs. 22.4%, $p < 0.001$). The overall fatality percentage was higher in fast jet and lower in rotary wing but the 2.2 fold difference between SD and non-SD accidents remained. Fast jet aircraft were associated with the highest accident rate (6.40 accidents per 100.000 flying hours) and highest lethality rate (38% of accidents resulted in fatality) although this improved over the period studied. Fixed wing aircraft (non-fast jet) were the least hazardous form of military flying and only comprised 3.9% of accidents in the survey. Accidents occurred most frequently amongst those aircrew with moderate flight experience (500 – 1000 total hours). This group also experienced SD most commonly and are being considered for supplementary SD training. Lack of recent flying experience, as a measure of competency, was not associated with the risk of incurring an SD accident.

A number of risk factors were identified which increased the risk of aircrew developing SD in the accident. These were night flight (2.1 fold), IMC (2.7 fold), poor backdrop (3.2 fold) and adverse CRM (3.8 fold). Accidents occurring whilst flying using NVG were infrequent and these did not appear to be associated with SD any more frequently than other night flight accidents. This is notably different to past US experience. The primary factor that led to the disorientation and accident was inattention (50% of accidents involving SD) rather than a disruptive sensory misperception, and of particular note, the disorientation remained unrecognised in 85% of cases at the point at which the accident became inevitable. The UK considers this lack of recognition and the inattention factor as clear areas for future intervention (see also Chapter 6).

In Greece over the 15-years period 1990 – 2005 62 major accidents (i.e. loss of life and/or aircraft) occurred. In 10 (16.7%) of these accidents SD was considered the main cause (one of main causes) and in 25 (40.3) SD was seen as a contributing cause. With an average of 100.000 flying hours per year, this implies a Class A accident rate per 100.000 flying hours of 4.1. For Class A accidents involving LSA/SD the rate per 100.000 flying hours is 2.7.

1.1.1.3 Conclusion

This data is summarized in Table 1.2. Direct comparison of the SD mishap data of different countries or services is difficult since it requires knowledge on the number of flying hours, type of aircraft, fixed or rotary wing, operating theatre, etc., data which is not easy available. This is even more difficult since the SD categorization applied may differ between countries and may change over time. For example, SD accidents under brownout conditions are by some air forces categorized as SD, whereas other air forces categorize them as Brownout. This obviously obscures the SD data bank. Similar problems occur with CFIT [12]. Nevertheless, the short overview of the incidence of SD-related class A mishaps data in the previous sections clearly shows that SD is a major cause of Class A aircraft accidents involving a relatively high number of fatalities in fixed wing aircraft. Rotary wing class A mishaps under brownout conditions on the other hand are numerous with, however, less fatalities, but a high number of casualties. It is therefore logical that effort is put into the development of technological SD avoidance tools and into the optimization of SD demonstration and training methods.

Table 1.2: International Comparison of SD Related Class A Mishaps

Country	Service	Ac Type	Early Period	Raw Data	%	Rate	TORs/Comments	Late Period	Raw Data	%	Rate	TORs/Comments
US	USAF	FAtt						93-02	25/189	13	0.36	SD, Class A, **FAtt only**
	USAF	UAV						94-03		5		Misperception error
	Army	RW	87-95	299/993	30		SD. All Class A-C	00-05	56/151	37		SD. **Operational** Class A-C. 61% in brownout.
	Navy	All						2004				Human error in 83%
Canada		All	82-92	14/62	23		SD. Cat A					
Czech Republic	Air Force	All	85-94	32/58			**LSA/SD**	95-05	15/17	88		**LSA/SD**
								91-05		23	1.6	SD Class A
Italy	Air Force	All						93-04	8/43	19	0.55	SD Class A
Netherlands	Air Force	All	80-95	7/39	18	1.0	SD Class A	96-05	1/9	11	0.3	SD Class A. Mainly F16 improvement
		FW	80-95	6		1.6	SD Class A					
France	Air Force	All						00-04	2/45	4		SD Class A
Germany	Bundeswehr	All						95-06	4/82	5	0.17	SD Class A. 50% due to recirculation
Sweden	Air Force	All	86-95	5/30	17	0.47	SD Class A	96-05	6/12	50	0.97	SD Class A
UK	All	All	83-92	48/193	25	1.03	SD Cat 4-5	93-02	37/112	33	0.88	SD Cat 4-5. Fatality 2.2 fold higher in SD. 50% due to inattention error.
Greece								90-05	35/62	56	2.7	**LSA/SD**

FAtt	Fighter Attack
LSA	Loss of Situational Awareness
TORs	Terms of Reference

1.2 SD COUNTERMEASURES

1.2.1 Technological Approach to Avoid SD

Different technologies are under development to make the human machine interfacing more intuitive, more logical, in fact more fitted to the human factor needs [13]. Some examples will be described briefly.

1.2.1.1 Instrument Displays / Novel Symbology

Until the advent of high-fidelity ground-based trainers capable of producing realistic SD illusions, the only effective countermeasure against spatial disorientation was the practiced instrument crosscheck. This crosscheck didn't necessarily prevent all types of SD, but it did (and still does) provide the pilot with a known method of preventing unrecognized situations which happen to be the most serious type of SD. Because better flight instruments have always been considered the best approach to solving the SD problem, laboratories throughout the world spent most of their efforts improving traditional flight instruments. This development is not bad. Many extremely valuable improvements have been observed over the years, a few of them are described below. However, flight instruments did seem to overshadow the need for improved ground-based trainers. This mismatch can be seen when visiting a physiology training unit to see what kind of tool is used to teach the nuances of SD such as the Barany Chair (circa 1920). Only within the past decade has serious progress been made on the development of the "SD Trainer". Before venturing into this world of ground-based SD devices, the authors believe it's prudent to review some of the most recent improvements made to traditional flight instruments. The following displays and concepts are by no means a complete list.

Global displays. The term "global" is used to designate a type of integrated display. In general, these displays incorporate all spatial, geographic and tactical information in a pictorial representation on one display surface. It may be multifunctional, but the idea is to keep all information on one window. The concept requires either a large, single, multi-function display (MFD) or a tight, seamless grouping of MFDs that appear as one. Global displays have shown improved performance in tasks associated with situation awareness and tracking [14,15]. As technology continues to advance, cockpits may eventually contain one large, continuous, graphical display surface for all instrument information.

Highway-in-the-sky (HITS). This concept (also known as Pathway-in-the-Sky) has been researched for several years and shown to benefit the pilot's primary spatial orientation [16]. This concept is similar to a flight director system in providing lateral course and climb and descent path guidance for a desired 3-D track. The HITS is different from a flight director in that it uses a symbolic path or roadway to represent the desired vertical and horizontal trajectory relative to the earth's surface as opposed to command steering bars or a single command steering cue. It appears more like the real world than current flight director systems and has received many subjective accolades from novice and experienced pilots alike [15]. The primary shortfall of HITS is its difficulty in guiding the pilot back to centerline once the relatively restrictive visual parameters have been exceeded – a problem similar to that experienced with the flight director when it reaches its limits of operation. This problem may be solved with a type of "director" arrow pointing to the correct path. The HITS concept is being studied as a potential primary flight reference for future general aviation aircraft [17]. It is also being analyzed for use on the HUD [18], as well as for head-down displays during ground taxiing.

Novel flight instrument display. Another interesting display concept was designed and developed by the British researchers Braithwaite and Durnford, while they were stationed on exchange duty at the US Army Aeromedical Research Laboratory in Ft. Rucker, AL [19]. This display, which they termed the "Novel Flight Instrument Display", presents the primary spatial orientation components in a comprehensive, purely symbolic (non-pictorial) format and integrates attitude, altitude, airspeed, heading, and vertical speed. The pilot has the option of selecting specific limits for each spatial orientation element and then performs a tracking task to maintain desired flight parameters. The presentation also allows the pilot to recognize and recover from an unusual attitude. Flight performance with this display has indicated a reduction in pilot workload.

OZ. The OZ display [20] is the latest and quite likely the most intuitive integrated design available today. The display breaks from tradition in virtually eliminating all alphanumeric characters and scales (except for heading) and replaces them with discrete symbols, colors, and shapes. The information is distributed throughout the entire display screen and contains a much larger (+/- 180 degrees horizontal) compressed, visual field. The pilot does not need to crosscheck any of the other flight instruments in order to maintain precise aircraft control (and does not have to turn his/her head to see out the side). Power symbology is provided implicit with the other control, performance and navigation symbology. Still & Temme [20] report that novice pilots quickly grasp the meaning of the unique symbology and can maintain a safe level of spatial orientation and navigation parameters with very little training. Most impressively, novice and experienced subject pilots performed exceptionally better with OZ during multiple-tasking and adverse flight conditions than with a traditional display. Several of Fitts' design principles are implemented into the strategy of this futuristic display.

1.2.1.2 Acoustic HUD

A three-dimensional auditory display presents sound from arbitrary directions spanning a sphere around the listener. Such displays have become feasible through the development of techniques for creating virtual sound sources using headphone presentation. Advantages in the cockpit, in addition to the information contained in the signal itself, are that relevant directional information can be conveyed using the natural sound localization ability of humans. Because it is common in high-workload tasks to present information primarily through the visual channel, use of the auditory channel shortens reaction times and is expected to reduce pilot workload, thus improving the overall situational awareness in the cockpit.

1.2.1.3 Tactile Displays (TSAS and TTTD)

The US Navy is developing a Tactile Situation Awareness System (TSAS) which is presented in a vest that the pilot wears and provides tactile cues to the pilot concerning attitude information of the aircraft. The US Army has also evaluated the TSAS and considers TSAS an SD countermeasure in rotary aircraft. The US Air Force, the UK and the Netherlands are also endorsing this tactile display concept using the TNO Tactile Torso Display (TTTD). For more information on tactile displays reference is made to the RTO report from TG-122 'Tactile displays in military environments' [21].

1.2.1.4 SORD

Because the US Air Force loses 6 pilots and aircraft each year on average to CFIT, the US Air Force's technological approach to SD countermeasures is the development of a Spatial Orientation Retention Device, or SORD. SORD is a multi-sensory cueing system that includes tactile, audio, and visual components that are integrated with a smart model of human orientation. The concept of SORD is to provide additional multi-sensory information to the pilot about his or her aircraft attitude. Many SD mishaps can be traced back to the fact that pilots became distracted or had channelized attention during flight and slipped into an unusual attitude because the motion of the aircraft was so gradual that it went undetected by their vestibular or somatosensory systems. They then hit the ground before they realized that their aircraft was not in the attitude they thought it was. SORD provides tactile, audio, and visual information to the pilot that is in addition to the usual Head Down Display or Head Up Display attitude information already available. SORD is an alerting system for the pilot. SORD has four components: tactile garment, 3-D audio, Helmet Mounted Display (HMD) symbology, and a Spatial Orientation (SO) assessor. The tactile garment, 3-D audio, and HMD symbology have been demonstrated in the Air Force Research Laboratory. A prototype of a tactile cueing system incorporating electric tactors has also been evaluated. The tactile cueing system 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. The off-boresight Arc Segment Attitude Reference symbology (ASAR), 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 [22].

1.2.1.5 auto-GCAS and auto-ACAS

The automated Ground Collision Avoidance System (auto-GCAS) locates continuously the aircraft spatially with respect to the scanned terrain and predicts continuously by means of an aircraft response model the aircraft's future recovery trajectory. Recovery is automatically initiated whenever the trajectory penetrates a preset distance from the terrain profile. By initiating the automated recovery after the moment pilots normally react to avoid a collision, the system is more acceptable to the pilot than the Ground Proximity Warning Systems (GPWSs). These last systems are often switched off by the pilot during nap-on-the-Earth flying [23]. Current Air-to-Air Collision Avoidance Systems provide audio and visual guidance to pilots, who then must take manual action. Such warnings work well for slow-manoeuvring transport aircraft that must keep far apart, but are ineffective for the fighter pilot whose mission requires close-formation flying and aggressive manoeuvring in the vicinity of other aircraft. Auto-ACAS, by comparison, waits until the last possible instant to perform; it waits until after the pilot missed his last chance to avoid a collision. When auto-ACAS takes control, it performs an aggressive maneuver to avoid the collision, and then returns control to the pilot. The system is not hardware, but "fail-safe" software in the aircraft's digital-avionics system. Each auto-ACAS equipped aircraft broadcasts its position and trajectory using a data link and receives identical information transmitted from other aircraft. The computers aboard each aircraft compare the data and identify conflicting flight paths. An operational system should allow miss distances of only a few hundred feet, just enough to prevent a collision [24].

1.2.1.6 TCAS

The Traffic-alert and Collision Avoidance System or TCAS is a system in which neighboring aircraft computer monitor each other to prevent midair collisions. A device in one jet's cockpit warns with an automatic voice 'traffic' and then commands the jet to climb, while the other jet is given a similar warning and commanded to descend. This system is primarily implemented in airliners and heavies. TCAS is not usually considered a SD countermeasure, but in light of a trend towards more automation (i.e. taking the pilot out of the decision process), we thought it worthy of at least a mention.

1.2.2 Training SD Avoidance

For many years implementation of SD avoidance training has been the objective of many flight surgeons, instructor pilots, flight psychologists and physiologist. The AGARD Working Group report No. 625 on Orientation / Disorientation Training of Flying Personnel, edited by Benson in 1974 [1], has served as a guide line about how to implement this training. Much of what has been written in that report is still valid today (see also Section 3.1). As a result in many air forces academic lectures on SD are part of the aerospace physiology lectures indeed, in the basic as well as in the refresher courses. There are, however, large differences between air forces in the amount of effort which is put into the more practical aspects, the demonstration of SD illusions, and the more advanced SD avoidance training. This certainly holds for in-flight SD demonstration and SD training, which is pretty rare in the various NATO countries. Time, relevant skill sets and costs are important issues for decision makers which hamper the in-flight demonstration and training sorties, despite the shown positive effects of in-flight SD demonstration in rotary wing aircraft [25]. Even a 10% reduction in the significant costs of these SD accidents by training, would be financially beneficial, not to speak about the lives that could be saved, and the reduced loss of combat readiness.

Positive high-tech developments in recent years have resulted in affordable highly sophisticated and flight realistic ground-based SD demonstration and training devices. Developments in the area of motion cueing allow simulation of flight profiles on the ground with realistic perceptual consequences for the pilot. Visual displays add to the realism with powerful displays and detailed data bases. Mission Simulation Training Centers also allow for NVG training (e.g. Mesa, Arizona). Since continuation training requires a cockpit environment and man in the loop control, it is especially in this area that ground-based SD training can make a significant step forward.

1.3 THE OBJECTIVE OF TASK GROUP TG-039

In the Technical Activity Proposal, submitted to the RTO in 2003, the objective of TG-039 was described as 'to produce recommendations for the improvement of aircrew training which should reduce the incidence of orientation accidents'. In that document justification for the proposal was summarized as 'Spatial Disorientation is a major cause of flight accidents. Demonstrating and training (student) pilots about the causes and consequences of SD is common practice in most armed forces. However, there are no standardized training procedures, nor are there standardized trainers/demonstrators. In view of interoperability it would be desirable to request at least a minimum level of aviator experience in this respect. Since there is a lot of dispute going on about how training should be implemented, and since training devices vary from small to large, from pure demonstrators to flight simulators, an assessment is needed on existing and desired courses'. Deliverable of the Task Group activities was to be a Technical Report.

During the preparation of the report two important publications became available. One is the excellent book 'Spatial Disorientation in Aviation' [26]. This book covers the entire spectrum of spatial disorientation in flight, from how the sensory systems are fooled in flight to technological SD countermeasures and SD avoidance training. The book is an invaluable reference source for SD related issues, but for the envisioned technical report much too detailed. Obviously, the 8th chapter on "Spatial Disorientation Instruction, Demonstration, and Training" by Braithwaite, Ercoline and Brown [2] was a rich source of information for the present report. Several contributors to the book are member of Task Group 39.

The second is a series of documents produced by Working Party 61 from the Air Standardization Coordinating Committee (ASCC) on SD training within the ASCC nations: Australia, Canada, New Zealand, United Kingdom and the United States [27,28,29,30,31,32,33,34]. These nations have evaluated their individual SD training programs and proposed standardized SD programs to facilitate interoperability within the participating nations. Several members of WP-61 also participated in TG-39. The envisioned technical report is more in line with these ASCC documents, although standardization is not the goal of the Task Group: The report should primarily assess the various aspects of SD training and provide recommendations about implementation of these SD programs in elementary pilot training and refresher courses. The structure of the report is shown in Section 1.3.1.

1.3.1 Report Overview

1.3.1.1 Executive Summary

The executive summary outlines the report. It shows the structure of the report, which should allow the reader to understand what should be taken into account in order to set up an effective spatial disorientation training program according to the NATO standards and advanced SD training programs for specific flight and environmental circumstances.

1.3.1.2 Chapter 1: Introduction

In this chapter Class A SD mishap statistics from several countries shows the continuing steady SD accident rate which indicates the need to proceed with technological approaches to reduce the SD incidents and to structure the SD countermeasure training. A short overview is provided about the technological approaches to counter SD, and the objective of the report is described, which is to produce recommendations for the improvement of aircrew training to reduce the incidence of spatial disorientation accidents.

1.3.1.3 Chapter 2: Current Approach to SD Training as per 2006

Air Forces of NATO countries have to comply with the STANAG 3114, in which, among others, the training requirements for SD countermeasure training are summarized. From a survey of SD countermeasure training in several air forces it is seen that classroom lectures are in accordance with STANAG 3114. However, STANAG 3114 does not specify the demonstration tools in detail. Consequently the survey shows a large variety of devices applied for SD demonstration and training, ranging from perfect simple to highly complex full flight simulators. In most countries the continuation training doesn’t differ much from the basic program. A conclusion from the survey is that ground-based SD demonstration and training is under development and certainly not standardized. This holds even more for in-flight demonstration and training sorties, which are structured in only a few countries.

1.3.1.4 Chapter 3: Ground-Based SD Demonstration and Training

The SD countermeasure training may be divided basically in three parts: academic instruction, demonstration and training. The *Academic Instruction* about SD is dealt with in Section 3.2. Examples for *demonstration* of basic visual and vestibular illusions underlying SD are provided in Section 3.3. A logical follow-up is the ground-based demonstration of in-flight SD illusions, as provided in Section 3.4. Part of these demonstrations is done with devices that also allow for in-the-loop control, which implies that this allows a transition between demonstration and *training*. In Section 3.5 examples are given about how SD training could be implemented in full flight simulators.

1.3.1.5 Chapter 4: In-Flight SD Training

Demonstration of SD-illusions is not restricted to ground-based devices. This chapter contains several flight profiles to demonstrate SD illusions *in-flight*. These are described in Section 4.1 for rotary wing and in Section 4.2 for fixed wing aircraft. In Section 4.3 in-flight SD training is discussed, i.e. learning flying procedures that anticipate disorientating circumstances and coping with the illusions once they have been encountered.

1.3.1.6 Chapter 5: SD Avoidance Training for Night Vision Devices

Although very helpful, night vision devices may provoke SD. In Section 5.1 the theory and examples for demonstration of phenomena underlying the SD provocation of night vision devices are provided. In Section 5.2 ground-based and in-flight training issues are discussed, especially the behavioral aspects to avoid SD.

1.3.1.7 Chapter 6: Optimization of SD Avoidance Training

There are many factors which determine together the SD training that should be provided during a pilot’s career. In fact this chapter allows to determine the necessary SD training requirements based on the in Chapters 3, 4 and 5 described examples, taking into account issues as general pilot training, refresher training, aircraft type, mission, costs, etc. This Chapter will consider a number of issues regarding spatial orientation training: the target audience, for example, pilots, navigators, aircrew (other than pilots), flight surgeons and aerospace physiologists; different pedagogical techniques in SD lectures to the above groups; timing of SD training (initial and refresher); the feasibility of having different phases of ground-based SD training in a pilot’s career; and who should be the trainers. Which illusions, sensory conflicts or traps that can predispose SD are essential or desirable to be demonstrated at which phase of the training will be considered separately for fixed and rotary wing aircraft. Recommendations might include a guideline for formal evaluation of the pilot’s knowledge on SD after training and general and practical advice to enhance SD awareness in aircrew and maintain the interest of spatial orientation in aeromedical operations for flight surgeons and aerospace physiologists.

1.3.1.8 Chapter 7: Instructors

Effective training requires professional trainers. In this chapter the requirements for instructors for SD countermeasure training are discussed.

1.3.1.9 Chapter 8: Aircrew Handout

This chapter provides a handout for pilots with need-to-know SD issues. The aim of these handouts is to make the spatial disorientation issue debatable among operational pilots.

1.3.1.10 Chapter 9: References

This chapter contains the references from all chapters.

Chapter 2 – APPROACH TO SD TRAINING

2.1 STANDARDIZATION AGREEMENT STANAG 3114

For NATO countries SD training should comply with Standardization Agreement STANAG 3114 Edition 7 as issued in 2003 entitled 'Aeromedical Training of Flight Personnel' [35]. The following extract about SD Training may be derived from this agreement. For the initial training no difference is made for fixed wing and rotary wing aircrew, so that part is presented only once. For the continuation training there is a slight difference in wording, so those sections are both replicated. Of interest is also the statement that "*All flight personnel engaged in flight operations will receive the continuation aeromedical training described in this STANAG at intervals up to 5 years*".

INITIAL AVIATION MEDICINE TRAINING OF FLIGHT PERSONNEL WHO ARE TO OPERATE FIXED WING / ROTARY WING AIRCRAFT

a) Academic Instruction

(19/15) Orientation and Disorientation. The anatomy and physiology of vestibular apparatus. Mechanisms of orientation on the ground and in flight. Spatial disorientation in flight, definition and mechanisms. Common types of disorientation in flight illustrated by examples. Factors leading to disorientation and its avoidance. The management of disorientation.

b) Practical Instruction

(4/2) Experience of Spatial Disorientation. The academic instruction on Spatial Orientation and disorientation should be reinforced by a practical demonstration of the effects of vestibular stimulation using a rotating chair or suitable disorientation device to provide each student with a personal experience of some of the common illusions.

CONTINUATION AVIATION MEDICINE TRAINING OF FLIGHT PERSONNEL WHO ARE TO OPERATE FIXED WING AIRCRAFT

a) Academic Instruction

(5) Spatial Disorientation. Revision of mechanisms underlying disorientation and of management of disorientation in flight. Discussion of recent incidents of disorientation and the lessons to be learnt from them.

b) Practical Instruction

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CONTINUATION AVIATION MEDICINE TRAINING OF FLIGHT PERSONNEL WHO ARE TO OPERATE ROTARY WING AIRCRAFT

21. Syllabus of the Course. The course is to include the following academic and practical instruction:

d) Spatial Disorientation. Revision of mechanisms underlying disorientation and of management of dis-orientation in flight. Discussion of recent incidents of disorientation and the lessons to be learnt from them.

Comparison with the STANAG Edition 5 of 1970 [1] shows that next to the lectures on the SD mechanisms and demonstration of illusions, now the practical management of SD takes a prominent place. In the draft version of STANAG 3114 Edition 8, instruction and practical experience should comply with

Air Standard 61/117/14 ‘Ground-based Demonstration of Spatial Disorientation’ [31] which has considerable consequences for the continuation training (see also Section 3.5 and 6.3.1.1). Flight safety is also an issue which is taken more and more into account in the academic instruction.

In the following section a survey is provided about the SD training as practiced per 2006 in several countries.

2.2 TRAINING AS IN SEVERAL COUNTRIES AS OF 2006

In line with STANAG 3114 SD training can be divided in *initial* SD training and *continuation* (refresher) SD training. SD training may also be different for *fixed wing* and *rotary wing* aircrew. Finally, each SD training may be divided in *academic* instruction and in *practical* instruction. It is of interest to see how different nations / services have implemented these STANAG regulations. This is summarized in Table 2.1. Although Australia and New Zealand are not member states of NATO, their SD training programs are also incorporated since they belong to the ASCC nations, which are standardizing their SD training programs. In Table 2.1 is displayed what kind of devices are applied (Barany Chair, dedicated motion based SD trainers, full flight simulators), what continuation training interval time is applied, as well as who serve as instructors.

Table 2.1: SD Training by Country

Type of SD Training	USAF	USN	USA	UK ARMY	UK RAF	UK NAVY	Canada	New Zealand
Classroom	LS, BC	LS,	LS	LS	LS	LS	LS	LS
Ground Based	BC	MSDD	BC	DISO	DISO	DISO	BC, GI	BC
Flight Sim Based	NVG	Nil	Nil	Lynx	Various	Various		
In-Flight SD Demo	4 A/C		Yes	Yes	No	No		
In-Flight to Overcome or manage SD	INR	UAT	UAT	UAT	UAT	UAT	No	UAT, Transition IMC - VMC
Refresher Training Frequency	5 yrs	4 yrs	If not fly within 180 days	5 yrs	5 yrs	4 yrs	5 yrs	3 yrs
Training Objectives & effectiveness	USD, Monitor Class A Mishap rate	USD, Written Exam	USD, Written Exam	Written Exam	Written Exam	Written Exam	NFP for refresher, Written exam for beginners	USD, No Eval
Training the Trainees	Flt Surg and Aero Phys	At NOMI, Flt Surg & Aero Phys	USASAM, Flt Surg	Army Spec in Aviat Med	Ex-mil Aircrew & Med Instr	Ex-mil Aircrew & Med Instr	Flt Surg, Aero Techs, BioSci Officers	Flt Surg

NOMI – Naval Operational Medical Institute
LS – Lecture Series
USD – Understanding SD
NVG – Night Vision Goggle
INR – In-Flight Recovery
G – Gyro I
GI – Gyro IPT
BC – Barany Chair
NFP – No Formal Process
V – Vertigon
UAT – Unusual Attitude Recovery Training
MSDD – Multi Station Disorientation Demonstrator

Type of SD Training	Spain	Czechia	Sweden AF/Nav/A	Greece	Italy	Germany	Australia	France	Netherlands
Classroom	LS,	LS	LS	LS	LS	LS, BC	LS,NVG	LS	LS, NVG
Ground Based	BC, GI	GI		DISO	BC, DISO	DISO	BC,GI	Centri fuge	BC, DISO, Desdemona
Flight Sim Based	No	No	UAT	IFR	No	Planned	No	No	No
In-Flight SD Demo	Navy	No	Yes		Yes	Yes	No	No	NFP
In-Flight to Overcome or manage SD	No	UAT	INR	IFR, UAT	NO	UAT, INR	INR	NFP	UAT
Refresher Training Frequency		5 yrs	Not Regulated	3 - 5 yrs	5 yrs	4 yrs	3 yrs	5yrs	4 yrs
Training Objectives & effectiveness	USD, No Eval. Query	NFP	NFP	Pre-exam, USD, LS exam, Eval	USD, written exam	USD, NVG	NFP	USD	USD, NVG,
Training the Trainees	Flt Surg & Av Med Course	Aero Phys	PTO's, IP's, Flt Surg	Flt Surg	Flt Surg & Aero Phys	GAFIAM, Flt Surg, Flt Inst	Flt Surg Av Med Course	AvMed Course	Aero Phys, Av Med Course

NOMI – Naval Operational Medical Institute
LS – Lecture Series
USD – Understanding SD
NVG – Night Vision Goggle
INR – In-Flight Recovery
G – Gyro I
GI – Gyro IPT
BC – Barany Chair
NFP – No Formal Process
V – Vertigon
UAT – Unusual Attitude Recovery Training
MSDD – Multi Station Disorientation Demonstrator

Since nations and services are in many respects hard to compare to each other, the information from Table 2.1 is also written in more detail in Sections 2.2.1 – 2.2.12.

2.2.1 United States

2.2.1.1 Organisation

Initial training in the US Air Force to counter SD is conducted during the pilot-trainee's undergraduate flight training program. There is a two-hour block of instruction for both the T-6 and the T-37 aircraft. There is no special SD training for the T-38. The official name for the flight-training program is Specialized Undergraduate Pilot Training (SUPT). The SUPT syllabus requires that the causes and consequences of SD be introduced during the Aerospace Physiology (AP) section, which is completed early in the year-long program. The entire AP section requires about 50 hours of instruction, while the SD portion is a 2-hour block of instruction titled by the same name. This same lesson plan is used for Undergraduate Navigation Training (UNT). The syllabus of instruction requires that each pilot-trainee be demonstrated an illusion using the Barany Chair (if available). The instructor can demonstrate the yaw reversal illusion (known as the graveyard spin, the Coriolis illusion, and nystagmus). It is common practice for instructors to select only a couple trainees for nystagmus. Each student is given at least one demonstration. The remainder of the class observes while the demonstrations are being conducted. Initial training to counter SD is conducted during the pilot-trainee's undergraduate flight training program. There are two aircraft now for specialized undergraduate pilot training, the T-6 and the T-37.

In the US Navy, initial SD training is conducted as part of the Naval Aviation Survival Training Program (NASTP), Aviation Physiology Curricula (NP-1) by the Naval Operational Medical Institute (NOMI) Pensacola, Florida. Initial SD training is conducted in conjunction with the initial aviation physiology and water survival training for aircrew. Typically this occurs in week 5 of the 6 week Aviation Pre-flight Indoctrination (API) program. API occurs before basic flight training.

2.2.1.2 Classroom

Classroom-based lecture series (1.5 hours) covers:

- Sensory systems involved in orientation – Anatomy and physiology of visual, vestibular, and somatosensory systems.
- Illusions – Discuss the types of illusions related to the limitations of the sensory systems.
- Physical and physiological factors affecting SD – Limitations of human information processing and attention, and loss of situational awareness.
- SD hazards with NVGs are covered as a specific topic.

2.2.1.3 Ground-Based Demonstration

In the US Navy, ground-based SD training is provided by the Multi-Station Disorientation Demonstrator (MSDD) which augments classroom lectures by demonstrating that spatial disorientation is a normal response to a variety of conditions. The MSDD enables students to experience spatial disorientation errors caused by the loss of reliable points of reference, conflicting sensory cues, and elevated inertial forces. All students experience at least one of the following effects: Sub-threshold rotation, Somatogyral illusion, Coriolis effect, Nystagmus, Oculogyral illusion, Somatogravic illusion, G-excess illusion, or Autokinesis.

Because of the increased night operations tempo of the USAF and the use of NVGs, the USAF has stepped up its NVG training, provided by AFRL/HEA at Mesa, Arizona. HEA trains many pilots each year in their Distributed Mission Trainers equipped with their Night Vision Training System. Pilots learn to use NVGs and are subjected to unusual attitudes and different illumination conditions in the simulator to increase the awareness of the disorienting effects of NVGs.

2.2.1.4 In-Flight

There currently is no specific section of the training syllabus for in-flight SD instruction in the US Air Force. Efforts are now being made to incorporate the in-flight demonstrations described in the ASCC AIR STD 61/117/13, entitled “In-Flight Demonstration of the Limitations of the Orientation Senses and Spatial Disorientation in High Performance Fixed Wing Aircraft” [32]. See also Chapter 4 for more details about this air standard.

Specific SD countermeasures training is embedded within a host of maneuvers each pilot-trainee must learn to earn his/her wings. For instance, unusual attitude recoveries must be practiced and proficiency maintained on almost all the in-flight sorties. In addition, specific procedures are learned and practiced should a wingman lose sight of lead when learning to fly formation. The intent of the procedure is to immediately obtain a safe separation distance between aircraft and for the wingman to quickly re-establish an instrument crosscheck for accurate spatial orientation. Also, during instrument flight training, the need for an efficient and accurate instrument crosscheck is constantly reminded to each pilot-trainee. (This point is made clear in the flight simulator portion mentioned above for the USAF). There are also a few pre-mission briefing items that may relate to some type of SD countermeasure, but all-in-all, specific training aimed at SD countermeasures is generally treated as a component needed to accomplish some other more specific flight maneuver or procedure.

There currently is no structured program of in-flight SD training in the US Navy. During the course of normal flying training, QFIs (Qualified Flight Instructors) may discuss a range of SD-related topics, but not in a structured format.

In-flight recovery from SD is taught by QFIs during primary and advanced stages of flight training. However, the emphasis is on the aeronautical recovery of the aircraft during unusual attitudes rather than an assessment of SD and the factors that allowed the unusual attitude to develop.

2.2.1.5 Refresher Training

In the US Air Force, information covered in the syllabus “Perception and Spatial Disorientation Issues Affecting Human Performance and Situational Awareness”, offers modified courses for helicopter and high-performance aircraft.

Topics cover:

- Special senses, including anatomy and physiology of the visual, vestibular, and kinesthetic systems, their limitations, and specific visual and vestibular illusions. NVDs are covered during the visual section. Also includes a section on auditory cues and spatial disorientation.
- Circumstances that contribute to disorientation and loss of SA, including NVDs. This also covers the corrective actions to rectify disorientation once recognized.
- Discussions of salient accidents and aircraft incidents which illustrate different facets of spatial disorientation.

Refresher training in the USAF occurs in two separate courses, one annually, the other, every five years. The first course, entitled “Instrument Refresher Course,” is a day long series of lectures covering primarily instrument flight procedures with a one hour brief on SD. It is preferably taught by an aerospace physiologist. As for the five-year recurrence training: There is a block of 45 – 60 minutes of instruction on SD during the aerospace physiology refresher course.

Refresher training, also known as continuation training, is usually an all day series of lectures. SD may often be a part of this series. If so, it would not be more than an hour. It is not required, although most instructors include some aspect of it. Most pilots are required to attend this annual refresher course. In addition, SD is sometimes the topic for discussion at the hour-long monthly flying safety meeting. Again, the specific subject of SD may or may not be addressed, depending on the instructor and the requirement to brief other material more relevant at the time.

In the US Navy, SD refresher training comprises an SD lecture required every 4 years as part of the platform-specific Naval Aviation Survival Training Program (NASTP) Aviation Physiology refresher training, and includes a review of visual and vestibular physiology, their sensory limitations, and specific visual and vestibular illusions.

2.2.1.6 Objectives and Evaluation

The stated objectives in the US Air Force for SD training are:

- To understand how perceptual illusions associated with the visual, inner ear, and seat-of-the-pants sensory systems lead to spatial disorientation and loss of situational awareness.
- To understand how loss of situational awareness associated with spatial disorientation impacts combat effectiveness and flying safety.
- To describe the corrective and preventative procedures for spatial disorientation.

No formal process has been established to monitor the effectiveness of SD training in the USAF.

In the US Navy, the terminal objective of SD training is to demonstrate knowledge of the physiological hazards and restrictions associated with SD in the flight environment. Enabling objectives include:

- Select the correct description for each of the four sensory systems, enabling orientation, equilibrium, and balance.
- Select the sensory systems providing the strongest and usually the most reliable orientation information.

- Identify the function of the vestibular system and its two subsystems, the semicircular canals and otolith organs.
- Determine the reason for the somatosensory systems unreliability in flight.
- Select the correct physiological explanations for specific vestibular illusions.
- Given an in-flight Spatial Disorientation scenario, identify the probable illusion experienced by the crewmember(s).
- Identify physical and physiological factors affecting Spatial Disorientation.
- Identify five methods used to prevent Spatial Disorientation.
- Identify seven procedures used to overcome Spatial Disorientation.
- Using a Spatial Disorientation Demonstrator, experience Spatial Disorientation and practice/ perform methods to maintain aircraft control while disorientated.

The effectiveness of SD training is validated by a written examination after the initial SD instruction. Naval Aerospace Medical Research Laboratory (NAMRL) continually monitors SD-related accident and incident rates.

2.2.1.7 Credentials SD Trainers

- The US Air Force instructors who become “instrument experts” must be graduates of the USAF Advanced Instrument School. This is a three-week program devoted to teaching instructor pilots the details of instrument procedures and the controlled airspace system (both national and international). The school is located at Randolph AFB, Texas. The instruction block lasts three hours and covers the costs, causes and countermeasures for SD.

In the US Navy, SD training is provided at NOMI for all Flight Surgeons, and Aerospace Physiologists. All SD training (lectures and ground-based demonstrations) is conducted at NOMI by Aerospace Physiologists.

2.2.2 United Kingdom

2.2.2.1 Organisation

Initial SD training in the Royal Air Force and Navy is conducted at the Centre for Aviation Medicine (Henlow) and follows NATO STANAG 3114 and ASCC AIR STD 61/117/1 [27] (see British Army, below, for description).

Army initial SD training is given in conjunction with the initial aeromedical physiology training, conducted at the outset of ab-initio flying training. RAF initial SD training is conducted at the completion of elementary flying training, in conjunction with other aviation medicine training. In addition, a short, classroom-based, introduction is given to some students prior to the beginning of elementary flying training. Non-pilot aircrew receive the aviation medicine training prior to commencing their basic flight training.

Royal Navy initial SD training is given in conjunction with aeromedical physiology training at the outset of ab-initio flying training.

2.2.2.2 Classroom

In all 3 UK services the classroom-based lecture series follows NATO STANAG 3114 and includes:

- Orientation overview – Definitions of orientation and disorientation, their importance to operational flight safety, and the relationship of the orientating senses.
- Special senses – Anatomy and physiology of the visual, vestibular, and kinesthetic systems, their limitations and common illusions (visual and vestibular).
- Psychology of orientation – Limitations of human information processing, attention, situational awareness, crew resource management, and perceptual errors such as errors of expectancy, and "break-off" and "giant-hand" phenomena. Illustration with a variety of recent SD accidents.
- SD hazards with NVGs are covered as a specific topic.

2.2.2.3 Ground-Based Demonstration

Ground-based SD demonstrations in the British Army are conducted using the DISO trainer at RAF Henlow. Students experience at least one visual and one vestibular illusion during their training. Non-participating students observe those illusions that they do not personally experience. The Lynx flight simulator is used to demonstrate IMC-related SD and train IMC procedures.

In the Royal Air Force, ground-based SD training is conducted using the DISO Trainer. Students experience at least one visual and one vestibular illusion during their training. Non-participating students observe those illusions that they do not personally experience. Scenarios designed to give students training in situations conducive to SD are used in the RAF Valley Hawk simulator. Similar helicopter-specific scenarios are currently under evaluation using the Griffin helicopter simulator at RAF Shawbury.

In the Royal Navy, ground-based SD training is conducted using the RAF DISO Trainer with students covering the same profiles as those used by RAF trainees. The Lynx flight simulator is used to demonstrate IMC-related SD and train IMC procedures. SD-specific scenarios are being considered for incorporation in simulator-based continuation training.

2.2.2.4 In-Flight

The British Army Air Corps has an established in-flight SD demonstration sortie that is exemplary. It is conducted during the operational training phase of ab-initio training and at all subsequent refreshers. The following sensory limitations are demonstrated:

- Sub-threshold manoeuvres.
- Decay of response of the semicircular canals to detect sustained angular rotation.
- Minor supra-threshold stimulation misinterpreted as change in attitude.
- Inadvertent descent (Type I).
- Poor perception of rotation and lateral movement in the hover.

In-flight demonstration of SD in the Royal Air Force and Royal Navy is conducted during the Tutor, Firefly and Tucano aircraft flying phases (for fixed-wing aircrew). QFIs demonstrate the following:

- The need for instruments – With the student's eyes open, fly a small barrel roll. Give control to the student to maintain straight and level with his/her eyes closed.
- How the natural senses cannot detect very low angular accelerations – With the student's eyes closed, roll very slowly (1 degree per second) to about 20 degrees. Ask the student for aircraft attitude. Repeat the demonstration, rolling to 40 degrees and then rapidly reduce bank to 20 degrees.

UA recovery training and inadvertent IMC is part of the general flying syllabus and is taught by AIs (Aircrew Instructors). The future remit of AIs may also be extended to cover some of the aspects of the in-flight SD demonstration sortie.

2.2.2.5 Refresher Training

SD refresher training in the British Army is conducted on a 5-yearly basis and includes lectures illustrated by SD accidents, discussion of aircrew SD experiences, and completion of the SD demonstration sortie.

SD refresher training in the Royal Air Force is conducted every 5 years and covers the NATO STANAG 3114 requirements. It offers also discussions on SD experiences from aircrew and is another opportunity to experience illusions using the DISO.

Royal Navy SD refresher training is required every 4 years, comprises a lecture series but does not include practical demonstration.

2.2.2.6 Objectives and Evaluation

The SD training objectives of the British Army are:

- "To understand the basic mechanisms of spatial orientation, appreciate the limitations of the orientation senses in flight, and how to best prevent and overcome SD" (classroom-based lectures); and
- "To augment the ground-based training in SD by demonstrating the limitations of orientation perception in flight … and to gain further understanding in the phases of flight in which SD is most likely" (SD demonstration sortie).

The SD training was validated by a written examination (for the lectures) and a questionnaire (after the SD demonstration sortie). In addition, the SD accident rate is monitored, and SD incidents are surveyed.

The training objectives of the Royal Air Force and Royal Navy are:

- "To describe the operation and limitations of the human orientation system and the effect that those limitations have on safe aircraft operations. A further objective is to give safe strategies to overcome sensory limitations with a view to mitigating the effects of any disorientation experience" (for lectures);
- "To allow aircrew to experience a disorientation episodes in a safe, controlled environment and hence, improve their awareness of the problem of disorientation" (for the Airfox DISO); and
- "To reinforce the lessons learned on the ground and provide further proof that the senses can be fooled…" (for in-flight SD training).

The effectiveness of SD training is validated by a written examination after the initial SD instruction. Centre for Aviation Medicine periodically monitors SD-related accident and incident rates.

2.2.2.7 Credentials SD Trainers

In the British Army, all SD training (lectures, ground-based training, and SD demonstration sorties) is conducted by Army Specialists in Aviation Medicine (SAMs) [who have completed the Diploma in Aviation Medicine]. Simulator-based training is conducted by AIs who have received additional briefings in SD from CA Avn Med (Army). Medical officers or ex-RAF aircrew deliver ground-based instruction (including the DISO) to all Royal Air Force and ab-initio Royal Navy aircrew at RAF Henlow. In-flight training is conducted by AIs.

2.2.3 Canada

2.2.3.1 Organisation

SD training is conducted centrally at the Canadian Forces School of Survival and Aeromedical Training during the initial aeromedical training given to novice aircrew.

2.2.3.2 Classroom

In Canada, the classroom-based lecture series covers:

- Sensory systems involved in orientation – Anatomy and physiology of visual, vestibular and somatosensory systems.
- Illusions – Discuss the types of illusions related to the limitations of the sensory systems.
- Psychology of SD – Limitations of human information processing and attention, and LSA.

2.2.3.3 Ground-Based Demonstration

Ground-based SD demonstration in Canada is provided by two mechanisms:

- Barany Chair – Demonstrates the limitations of the vestibular system and basic vestibular illusions.
- Vertigon (Flightmatic Inc) – Induces a Coriolis illusion after sustained rotation around the yaw-axis.

The Gyro IPT (Integrated Physiological Trainer, manufactured by ETC) is used to demonstrate Coriolis and somatogyral illusions in novice pilots only. Due to the limited rotation about axes, its benefit over the Barany Chair and Vertigon has not been conclusively established.

2.2.3.4 In-Flight

In Canada, there is no structured in-flight demonstration of SD, but some QFIs mention SD-relevant points during training sorties. There is no structured or standard in-flight UA recovery training. During training sorties, QFIs place the aircraft in an unusual attitude and then get the student to execute the appropriate recovery actions – the emphasis is on the recovery of the aircraft rather than on the factors contributing to the development of spatial disorientation which allowed the unusual attitude to occur.

2.2.3.5 Refresher Training

Re-certification training is conducted every five years thereafter, typically at the squadron level. While no re-certification course CTS (Course Training Standard) or CTP (Course Training Plan) exist, it is understood that re-certification training consists of the major Enabling Objectives (EOs) of the Initial course Performance Objectives (POs). This training is conducted over a period of a half-day and includes briefings on specific illusions pertinent to the type of aircraft flown by those being briefed. It also includes review briefings on the other aeromedical training aspects covered in the initial training course. Finally, there are no formal evaluation tools nor any formal SD recovery exercises or drills.

2.2.3.6 Objectives and Evaluation

Canadian Forces Commanders require pilots who possess the knowledge and skills necessary to perform many tasks in the presence of physiological hazards. The objective of the training is to provide Canadian Forces Pilots with the skills and knowledge to prevent, recognise, and control the physiological effects of flying including spatial disorientation. SD training is conducted as part of the Initial Pilot Aeromedical

Training Course conducted over five days. SD forms seven of the 26 EOs of the course and includes the following objectives:

- Explain the principles of vision.
- Explain the principles of night vision (unaided).
- Identify and manage the visual hazards of flight.
- Identify visual illusion.
- Identify the limitations of the use of NVGs.
- Describe the effects of spatial disorientation.
- Describe situational awareness and motion/simulator sickness.

The students' progress was monitored during the training by administering a written Enabling Check (EC) and verbal feedback based on performance during simulation. Continuous feedback was given to the trainees regarding their progress in the course and to identify any difficulty.

2.2.3.7 Credentials SD Trainers

SD training is provided at the School of Operational Aerospace Medicine for all flight surgeons, aeromedical technicians, and bioscience officers in Canada.

2.2.4 Australia

2.2.4.1 Organisation

Initial SD training in Australia is conducted through the Institute of Aviation Medicine. For pilot aircrew of all services, the training is conducted during initial fixed-wing flying training in conjunction with initial aviation medicine training. Australian SD training is performed in conjunction with the initial aviation medicine for aircrew lectures. Early in the Basic Flying Training phase student aircrew are given the initial aviation medicine for aircrew lectures (including SD) and the Barany Chair demonstration. At the completion of this phase of flying training, all aircrew attend AVMED for SD demonstrations using the Gyro-Lab (as well as a hypobaric chamber exposure) before completing a second fixed-wing flying phase.

2.2.4.2 Classroom

The lecture series covers:

- Special senses – Anatomy and physiology of visual and vestibular senses, including discussions of specific visual and vestibular illusions.
- Spatial disorientation – The role of the vision, vestibular organs, and proprioceptors in maintaining spatial orientation, the sensory limitations and the development of false orientation perception (including the circumstances where spatial disorientation is likely). Includes discussion of the corrective actions to overcome/dispel false perceptions and re-establish spatial orientation.
- Human factors and disorientation – Topics include human information processing, errors of expectancy, central illusions such as "giant hand" and "break-off" phenomena.
- SD with NVG operations are covered in detail during the NVG instructor course and the training of novice NVG aircrew.

2.2.4.3 Ground-Based Demonstration

In the Royal Australian Air Force, ground-based SD demonstrations are conducted in two devices.

- Barany Chair. The Barany Chair is used to demonstrate the limitations of the semicircular canals, subthreshold rotation, and the Coriolis Effect. This is conducted during the initial aviation medicine training during Basic Flying Training.
- Gyro-1 (developed by ETC). This demonstration is conducted during the transition from basic flying training to the subsequent fixed-wing flight phase. The students experience one of the following illusions – autokinesis, the Leans, Coriolis Effect, graveyard spin, nystagmus, and oculogyral illusion, with the non-participating students observing.

Instrument flying training, including UAR, is performed in the S70 Blackhawk simulator.

2.2.4.4 In-Flight

There is no structured programme of in-flight SD training in Australia. During the course of normal flying training, QFIs may discuss a range of SD-related topics, but not in a structured format. In-flight recovery from SD is taught by QFIs during flying training, however, the emphasis is on the aeronautical recovery of the aircraft and IFR-skills rather than an assessment of SD and the factors that allowed the unusual attitude to develop.

2.2.4.5 Refresher Training

SD topics are included in the aviation medicine refresher training for all aircrew, 3-yearly for the RAAF and Army. Topics include a review of visual and vestibular physiology, their sensory limitations, and specific visual and vestibular illusions. SD with NVGs is also covered during the refresher training, as is a discussion with aircrew regarding their SD experiences.

2.2.4.6 Objectives and Evaluation

No formal process has been established to monitor the effectiveness of SD training in the Australian Defence Forces.

2.2.4.7 Credentials SD Trainers

SD training in the Australian Defence Force is conducted jointly by medical officers, Aviation Physiology Training Officers (APTOs), and qualified flying instructors (QFIs). All “train the trainer” courses are conducted at AVMED – the Health Specialist Officer course for medical officers, the Aviation Physiology Training Officer course for APTOs, and the Qualified Flying Instructor Aviation Medicine Refresher course for QFIs. Medical officer instructors at AVMED are required to have a Diploma in Aviation Medicine, and non-medical instructors are APTOs who have undergone additional training in aerospace physiology with the USAF.

2.2.5 New Zealand

2.2.5.1 Organisation

The training is provided in association with initial aviation medicine training for aircrew. This is given early in the Basic Flying Course prior to commencing practical flight training. SD training is also given to experienced aircrew during the QFI course.

2.2.5.2 Classroom

The New Zealand air force provides a classroom-based series of three lectures that cover:

- Spatial disorientation (definition and importance in flying);

- Mechanisms of spatial orientation;
- Describe common vestibular and visual illusions (and describe importance in SD);
- Explain means by which SD can be reduced and in-flight recovery actions; and
- Includes use of training video.

2.2.5.3 Ground-Based Demonstration

Ground-based demonstration of SD in New Zealand is provided by Barany Chair, used to demonstrate the limitations in semi-circular canal physiology and vestibular illusions. This is given during the spatial disorientation component of the initial aviation medicine course.

2.2.5.4 In-Flight

There are no specific SD training flights in New Zealand and QFIs do not have a structured list of SD scenarios or illusions that they demonstrate during training sorties. Student pilots are placed in an unusual attitude with their eyes closed, asked to describe their orientation, and then asked to open their eyes and re-orientate prior to taking the aircraft controls. They are also trained in the transition from IMC to VMC.

2.2.5.5 Refresher Training

In New Zealand, SD and associated human factors are covered in the 3-yearly aircrew aviation medicine refresher course.

2.2.5.6 Objectives and Evaluation

New Zealand follows the following training objectives and measures:

- Outline the mechanisms of orientation;
- Identify the anatomy and functions of the vestibular system;
- Describe the function of the proprioceptors;
- Outline the various types of orientation;
- Identify situations in which disorientation may occur;
- Describe the anatomy and physiology of the visual system;
- List cues used in depth perception;
- Understand the physiological and perceptual limitations of vision;
- Identify situations in which visual illusions can occur; and
- List the visual problems associated with various types of flight.

Apart from SD and vision questions in the final exam, there is no formal SD evaluation process.

2.2.5.7 Credentials SD Trainers

Aircrew undergoing QFI training are given specific refresher training on SD in New Zealand.

2.2.6 Czech Republic

2.2.6.1 Organisation

The initial SD training is provided in association with the aviation physiology course for student pilots. This course is given before practical flight training.

2.2.6.2 Classroom

Classroom lectures (four hours, lecturer is MD) consist of psychology, Human Factor issues and LSA/SD problems (definition, physiology of sensors, illusions, recovery actions, etc.). The SD problem is also treated within the IFC theoretical lectures (by a pilot instructor).

2.2.6.3 Ground-Based Demonstration

Ground-based demonstration of SD with the GYRO IPT II shows the limitations of sense of attitude during visual and vestibular illusions during the initial pilot aeromedical training conform NATO STANAG 3114 [36]. This is given during pilot studies. The spatial disorientation demonstration takes about one hour. It consists of two phases. At first a passive demonstration is provided in the dark (with a group of four students, one inside the GYRO) of the limitations of the sensory systems (illusions: autokinesis, vestibular subthreshold, somatogravic, somatogyral, oculogyral, leans, Coriolis). After familiarization every student pilot controls the GYRO IPT II himself and experiences SD (illusions: false horizon (day), somatogyral – spin recovery, runway width, leans, sloped runway, oculogyral, somatogyral, black hole approach, Coriolis).

2.2.6.4 In-Flight

There are no specific SD training flights in Czech AF. In-flight demonstration (by pilot instructor) includes only unusual attitude recovery and is given every 6 – 12 months. Pilots are also trained in IMC flying – 25% of flight hours.

2.2.6.5 Refresher Training

SD training is given to experienced pilots during the continuation aeromedical training course minimally every five years according to NATO STANAG 3114. The SD training consists of theoretical lectures (one hour) and a flight with some illusion profiles in the simulator GYRO IPT II (also one hour). Leans and somatogyral illusion are obligatory.

2.2.6.6 Objectives and Evaluation

The Czech AF adheres to the following training objectives:

- Outline of the mechanisms of spatial orientation;
- Shortly explain physiology and limitation of visual, vestibular system and other sensory systems;
- Outline the various types of disorientation;
- Identify situations in which disorientation may occur; and
- Explain common types of illusions.

2.2.6.7 Credentials SD Trainers

All SD training is conducted by MD (with Diploma in Aviation Medicine) in the Institute of Aviation Medicine. They are qualified for GYRO IPT SD training by AMTI ETC USA. All training courses for flight instructor (ex-military aircrew) for GYRO trainer are done by MD.

2.2.7 Italy

2.2.7.1 Organisation

Ground-based SD training is conducted centrally at the ITAF Aerospace Medicine Dept. (Pratica di Mare AFB). The basic training is provided in association with initial aviation medicine training for aircrew. This is given early in the Flying Course prior to commencing practical jet flight training (in the US on T-37 or in Italy on MB-339). In agreement with the STANAG 3114, SD training is also given every 5 years to experienced aircrew during the refresher aerospace physiology course. For pilots and navigators employed in aero-tactical squadrons and helicopters, or as flight instructors, specific (basic and advanced) courses on SD are held.

2.2.7.2 Classroom

Classroom-based series of lectures are provided, that cover:

- Spatial orientation and disorientation (definition and impact on flight safety);
- Mechanisms of spatial orientation;
- Common vestibular and visual illusions and their importance in SD onset;
- Psychological aspects related to SD (including the “Giant Hand” and the “Break Off” phenomena);
- Particular operational environments where the SD onset can be facilitated (NVG use, effects of rapid onset accelerations, sleep deprivation, etc.);
- Explain means by which SD can be reduced and analysis of possible in-flight recovery actions; and
- The program for specific courses on SD also includes the use of training videos.

2.2.7.3 Ground-Based Demonstration

Ground-based demonstration of SD is provided by a rotatory chair (with possibility of off-axis rotations), used to demonstrate the limitations in semi-circular canal physiology (sensory threshold and adaptation, nystagmus) and some vestibular illusions (Coriolis and Purkinje phenomena, pitch-up sensations during an x-axis acceleration). This is given during the spatial disorientation component of the initial aviation medicine course. For more advanced training (i.e. refresher and specific courses on SD) a flight simulator device (Airfox DISO) is also utilized to run the illusions within an aviation environment.

2.2.7.4 In-Flight

With the exception of helicopter pilots at the beginning of their flight career on helicopters, there is no specific in-flight SD training in the ITAF. Pilot instructors do not have a structured list of SD scenarios or illusions that they demonstrate during training sorties, although recovery from unusual attitudes is a standard situation during the flight training course of student pilots. During the SD course for helicopter student pilots, which is held at the ITAF Aerospace Medicine Dept. (Pratica di Mare AFB), i.e. within an aeromedical environment, a group of 4 trainees performs 5 different flight profiles that evoke vestibular illusions. One subject (eyes closed) is exposed to the illusion, while the others listen to his/her description of what is going on. Each profile includes a pre- and post-illusion very short briefing, which is held by the SD instructor (Medical Officer), who is part of the helicopter crew.

2.2.7.5 Refresher Training

Standard aero-physiological training in the ITAF recurs every five years (i.e. in accordance with the STANAG 3114). Within this training, there is a block of 2 hrs of theoretical instruction on SD, together with 3 more hrs dedicated to practical exercises. A specific advanced course on SD is also provided to those aircrews considered at risk for SD (see above point 2.2.7.1).

2.2.7.6 Objectives and Evaluation

The stated objectives in the ITAF for SD training is to give adequate theoretical and practical knowledge on SD in flight, possibly with specific details on the type of flight missions which are usually conducted by the trainees. More advanced courses aim at refreshing knowledge on the topic, and add further information and practical exercises dedicated to the specific trainees' flight activity.

At the end of each course, a questionnaire with a few easy questions on SD is administered to the classroom (a discussion follows the correction of questionnaires); moreover, a second questionnaire dedicated to criticism and possible suggestions for the course improvement is also submitted.

2.2.8 The Netherlands

2.2.8.1 Organisation

Ground-based SD awareness training is centralized in Soesterberg at the RNLAF Centre for Man and Aviation (CML), and at TNO Human Factors. The topic SD is covered during the initial Aerospace Physiology course at the CML, which takes place just prior to practical flight training,. Two months later, early in the Flying Course, more extensive practical demonstrations are given at the facilities of TNO. Refresher training is given in association with recurrent Physiology training.

2.2.8.2 Classroom

The 2hr classroom lecture at the CML covers:

- Physiology of human sensory systems;
- Mechanisms of spatial orientation and disorientation;
- Common visual and vestibular illusions and their importance to flight safety;
- Physiological conditions that facilitate SD (sleep deprivation, alcohol); and
- Definition and classification of SD.

The lecture is illustrated by video fragments, and a syllabus. Immediately following this lecture, each student gets 30 minutes of practical demonstration as a first familiarization with SD.

2.2.8.3 Ground-Based Demonstration

Ground-based demonstrations at the CML employ a flight simulator device (DISO). For initial familiarization of student pilots, primarily passive illusions are shown, i.e. without an active flight task. For refresher purposes, the device is capable of producing active (man-in-the-loop) illusions. Demonstrations at TNO currently take one day, and employ equipment of the vestibular laboratory (3D rotating chair, tilting room), which is suitable for showing elementary vestibular and visual illusions underlying in-flight spatial disorientation. The course also includes a one hour demonstration of the limitations of night vision devices to maintain a correct spatial orientation (NVG, thermal imagery). The motion-base simulator DESDEMONA is used for SD demonstration to student pilots, and for SD avoidance and recovery training for continuation training.

2.2.8.4 In-Flight

The RNLAF does not structurally conduct in-flight SD demos, but trains unusual attitude recovery.

2.2.8.5 Refresher Training

Refresher courses on SD are provided at the CML in association with aeromedical training. Jet and helicopter pilots receive refresher training immediately after completion of their flight training. The SD refresher consists of actively flown illusions in the flight simulator devices, during which the related theory is discussed. A second refresher session is given three years later. From then, refreshers are given every five year. In addition, SD is dealt with during recurrent NVG training.

2.2.8.6 Objectives and Evaluation

The purpose of the SD awareness training is to give pilots a thorough understanding of their sensory systems, and their response to flight-related motion stimuli. In the initial aerospace physiology course during Ground school, the pilots' knowledge is evaluated through a written exam. Furthermore, the pilots can express their appreciation of the TNO course by means of an anonymous questionnaire at the end of the course.

2.2.9 France

2.2.9.1 Organisation

SD training in France is conducted at the Department of Aviation Medicine (Mont de Marsan). Aeromedical officers give the lectures.

2.2.9.2 Classroom

French air force provides a classroom-based series of two lectures. The first one covers sensory systems involved in orientation and common vestibular and visual illusions. The second one describes visual illusions observed in aeronautics.

2.2.9.3 Ground-Based Demonstration

Ground-based SD training is provided by a centrifuge (linear acceleration 1.04 G, pitch and roll tilt ± 40 deg.). Pilots experience autokinesis, somatogyral, somatogravic (pitch up, pitch down and inversion) and Coriolis illusions.

2.2.9.4 In-Flight

There is no structured programme of in-flight SD training in France.

2.2.9.5 Refresher Training

There is no structured refresher training in France. However, medical officers could decide to give some SD course to the pilots of their base depending on the flying mishaps.

2.2.9.6 Objectives and Evaluation

The SD training objectives are to allow pilots to experience a conflict between what they feel the aircraft is doing and what the flight instruments show that it is doing. The conclusion is that the use of flight instruments is the procedure to overcome SD. No process has been established to monitor the effectiveness of SD training in France.

2.2.10 Germany

2.2.10.1 Organisation

The German Air Force Institute of Aviation Medicine (GAFIAM) is responsible in the Division Aviation Physiology for the basic and continuation aeromedical training of the entire flight personnel (Air Force, Army, Navy, and Medical Corps) in accordance with STANAG 3114. The SD training is integrated in the aeromedical training for aircrew. Theses lectures and the SD-demonstrations in the ground-based training device are given prior to the first practical flight training. SD training is also given to experienced aircrew during the continuation training courses.

2.2.10.2 Classroom

The classroom lectures include:

- Special senses – Anatomy and physiology of visual and vestibular senses, including discussions of specific visual and vestibular illusions.
- Spatial disorientation – Type I and type II SD, spatial orientation.
- Spatial disorientation – The role of vision, vestibular organs, and proprioceptors in maintaining spatial orientation, the sensory limitations and the development of false orientation perception (including the circumstances where spatial disorientation is likely).
- Discussion of the corrective actions to overcome false perceptions and re-establish spatial orientation: believe and trust the instruments.
- Human factors and disorientation – Topics include human information processing, errors of expectancy, central illusions such as “giant hand” and “break-off” phenomena.
- SD with NVG operations is covered in detail during the night vision lectures and night vision demonstrations.

2.2.10.3 Ground-Based Demonstration

The Barany chair is still used in the classroom lectures in basic physiological courses to aircrew for basic understanding Coriolis effects and individual movement percepts above and below the individual threshold.

Since 2005 the GAF ground-based SD training is provided by the DOT Disorientation Trainer (AMST Airfox) which augments classroom lectures by demonstrating that spatial disorientation is a normal response to a variety of conditions. DOT enables students to experience spatial disorientation errors caused by the loss of reliable points of reference, conflicting sensory cues, and elevated inertial forces. All students experience at least two of the following effects: Sub-threshold rotation, Somatogyral illusion, Coriolis Effect, Nystagmus, Oculogyral illusion, Somatogravic illusion, G-excess illusion, or Autokinesis. The lectures are designed for experienced pilots, experienced non-pilot aircrews, student pilots and medical (enlisted) aircrews.

The SD-training varies between “flying the DOT by the trainee” with the task, to detect typical forms of SD and “demonstration flights” by the instructor pilot outside the simulator, who demonstrates illusions and effects to the student “as a passenger”.

2.2.10.4 In-Flight

The German Air Force has currently no specific syllabus for in-flight SD instruction. During flight it is annually required to have a graded unusual attitude recovery during check ride. This is usually done by an

Instructor Pilot, placing the pilot with eyes closed in an unusual attitude, giving back the aircraft and having done the recovery by the pilot with eyes open. During pre-flight briefing it is required to emphasize SD-items, especially when bad weather conditions are expected during flight.

However, during Basic Flight Training every student pilot has to do a special syllabus item on T-37 aircraft, demonstrating some SD (sub threshold manoeuvres, supra threshold manoeuvres, inability of the semicircular canals to detect sustained angular rotation).

2.2.10.5 Refresher Training

Continuation training is provided every four years at the GAF Institute of Aviation Medicine, Division "Aviation Physiology", during the Aerospace Physiology Training Course, in accordance with STANAG 3114. The SD issues are lectured first in a one hour classroom presentation and second in an additional one hour training in the DOT (AMST Airfox) with a group of up to 6 trainees. Lectures and practical SD-training are presented by aerospace physiology officers (pilot instructors).

2.2.10.6 Objectives and Evaluation

The training objectives in the German Air Force for SD training are to:

- Understand the function of the vestibular system and its two subsystems (semicircular canals and otolith organs);
- Understand the function of the proprioceptive system;
- Understand how perceptual illusions of the sensory system can lead to Spatial Disorientation;
- Understand the anatomy and physiology of the visual system and its limitations; and
- Understand the corrective and preventive procedures to avoid spatial disorientation.

No formal process has been established to evaluate the effectiveness of SD training in the German Air Force, except for a written examination in the flight surgeon course.

2.2.11 Sweden

2.2.11.1 Organisation

Education/training consists mainly of lectures during basic flight training in combination with actual flight training. No formalized ground training is available today.

2.2.11.2 Classroom

Lectures covering flight physiology are administered by flight surgeons and flight physiology officers and are focused on vestibular, visual and darkness related disorientation. Spatial disorientation is also integrated in the situational awareness concept.

2.2.11.3 Ground-Based Demonstration

There is no ground-based SD demonstration today. Unusual attitude recovery training is performed in the simulator. The Swedish Dynamic Flight Simulator demonstrates the G-excess illusion and Coriolis stimulation, but this is not the main target of training. Helicopter pilots do not train in the DFS.

2.2.11.4 In-Flight

In-flight recovery from SD is integrated in the flight training process. No formalized scheme.

2.2.11.5 Refresher Training

There is no formal process regulating training intervals or components regarding SD.

2.2.11.6 Objectives and Evaluation

Flight physiology training mainly follows a crew-to-crew concept and main objective is safe pilot behaviour in *real* flight.

2.2.12 Greece

2.2.12.1 Organisation

The Hellenic Centre for Aviation Medicine (HCAM-Athens) is responsible for the basic and continuation aeromedical training of entire flight personnel in accordance with STANAG 3114. The initial SD training is provided in association with the aviation physiology course for aircrew. This course is given before practical jet flight training (T-6 and T-2). In addition, a short, classroom-based, introduction is given to students' pilots prior to the beginning of elementary flying training at the Hellenic Air Force Academy. Aeromedical officers give the lectures. Finally, instructor-pilots also treat the SD problem within the IFC Flying theoretical lectures. In agreement with the STANAG 3114, SD training is also given every 3 – 5 years to experienced aircrew during the refresher aerospace physiology course. All SD training is conducted by MD (with Diploma in Aviation Medicine) at HCAM-Athens. They are qualified for the DISO trainer by a special training at AMST, AUSTRIA.

2.2.12.2 Classroom

The classroom-based lecture series follows NATO STANAG 3114 and includes:

- Orientation overview – Definitions of orientation and disorientation, their importance to operational flight safety, and the relationship between all of the orientating senses.
- Special senses – Anatomy and physiology of the visual, vestibular, and kinesthetic systems, their limitations and common illusions (visual and vestibular).
- Psychology of orientation – Limitations of human information processing and attention, and loss of situational awareness.
- SD hazards with NVGs are covered as a specific topic during the night vision lectures and night vision demonstrations.
- The lecture also includes the use of training videos.

2.2.12.3 Ground-Based Demonstration

Ground-based SD demonstrations in the Hellenic Air Force are conducted using the DISO trainer (AMST Airfox) at HCAM Athens. Students experience at least four of the following effects (observed by non-participating students): Sub-threshold rotation, Somatogyral illusion, the Leans, Coriolis Effect, graveyard spin, Nystagmus, Oculogyral illusion, Somatogravic illusion, G-excess illusion, or Autokinesis (NATO STANAG 3114). For initial familiarization of student pilots, primarily passive illusions are shown, and for refresher purposes, the device is capable of producing active illusions (see Table 2.2). The spatial disorientation demonstration takes at least one hour. The course also includes a demonstration of the limitations of night vision devices.

Table 2.2: SD Training Sorties (Standard Profiles for SD Training)

Candidates	*AUTOKINESIS*	**Jet Pilots**	*LEANS*	**Transport Aircraft Pilots**	*LEANS*	**Helicopter Pilots**	*LEANS*
	NYSTAGMUS		*DARK TAKE OFF*		*DARK TAKE OFF*		*DARK TAKE OFF*
	SOMATOGYRAL ILLUSION		*SIZE-DISTANCE / HEIGHT-DEPTH ILLUSIONS*		*SIZE-DISTANCE/ HEIGHT-DEPTH ILLUSIONS*		*SIZE-DISTANCE/ HEIGHT-DEPTH ILLUSIONS*
	SOMATOGYRAL ILLUSION		*BLACK HOLE APPROACH*		*BLACK HOLE APPROACH*		*BLACK HOLE APPROACH*
	CORIOLIS PASSIVE		*FALSE HORIZON CLOUDS ILLUSION*		*FALSE HORIZON GROUND LIGHTS ILLUSION*		*FLICKER VERTIGO*
			GRAVEYARD SPIN		*GRAVEYARD SPIN*		*FALSE HORIZON GROUND LIGHTS ILLUSION*

2.2.12.4 In-Flight

There is no structured programme of in-flight SD training in Greece, although recovery from unusual attitudes is a standard situation during the flight-training course of student pilots. They are also trained in the transition from IMC to VMC. Finally, during pre-flight briefing it is required to emphasize SD-items (bad weather, over sea flying).

2.2.12.5 Refresher Training

The SD refresher training course is given to experienced pilots during the continuation aeromedical training course (NATO STANAG 3114) minimally every 3 – 5 years. The SD training consists of one-hour theoretical lectures (Topics include a review of visual and vestibular physiology, their sensory limitations, and specific visual and vestibular illusions), and a flight with at least four illusion profiles using the DISO trainer (AMST Airfox) at HCAM Athens (also one hour). SD with NVGs is also covered during the refresher aeromedical training.

2.2.12.6 Objectives and Evaluation

The training objectives in the Hellenic Air Force for SD training are to:

- Understand the anatomy, physiology and the function of the visual system, of the vestibular system, of the proprioceptive system and the limitations of human physiology in-flight.
- Understand how perceptual illusions of the sensory system can lead to spatial Disorientation.
- Identify situations in which disorientation may occur.
- Describe the effects of spatial disorientation.
- Describe the various types of disorientation.

- Identify the limitations of the use of NVGs.
- Describe situational awareness and motion/simulator sickness.

The SD training is validated by a written examination (for the lectures) and a questionnaire (after the SD demonstration sortie). Finally, the pilots can express their criticism and possible suggestions for the course improvement by means of an anonymous questionnaire at the end of the course. No process has been established to monitor the effectiveness of SD training in Greece.

2.3 CONCLUSIONS

The summaries of the SD training courses as provided in the previous sections shows that the approach is quite different per country. There is a general agreement about the contents of the academic instruction, but the demonstrations and training courses clearly show different approaches. This is in some cases understandable because of the differences in environmental circumstances or operational theatre. The aim of this report is therefore to provide sufficient information about all the aspects of understanding and demonstrating spatial disorientation and training spatial disorientation countermeasures to allow the staff to make an adequate choice for SD training that benefits flight safety in his/her country.

Chapter 3 – GROUND-BASED SD TRAINING

3.1 INTRODUCTION

It is generally recognized that Spatial Disorientation 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 pilot's career will change with the development of 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. This part is dealt with in Section 3.2. 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 (Sections 3.3 and 3.4) or with in-flight demonstrations (Sections 4.1 and 4.2). The third part comprises the SD training, i.e. the (student) pilot learns how to avoid SD and how to handle when SD is encountered. This may be accomplished with in-flight SD training (Section 4.3) and partly with advanced ground-based SD devices with a flight simulation capability (Section 3.4) and with full flight simulators (Section 3.5). The Task Group realizes that different cross-sections are possible, but preferred to describe all the ground-based related SD training issues in Chapter 3 and all the in-flight related SD training issues in Chapter 4. Night Vision Devices have also some SD provoking peculiarities. These aspects will be dealt with in Chapter 5.

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-DoF motion platforms – so far only possible for a limited number of SD illusions. Because of the major role of motion cueing in these SD devices, in Section 3.4.3.6 special attention is paid to the underlying principles of motion cueing.

That correct motion cueing is important may be understood by comparison to what happens with simulator training of transport pilots. Here all types of abnormal and emergency events belong to the training syllabus. Most of these special events are simulated with a special effect toolbox. Mostly, for each special event only one simulation realization was developed. It turns out that pilots try to link an event in real flight with their simulation experience, because pilots know most of these events only from simulation training. This has led to wrong interpretations of real events in flight, with in some cases dangerous situations due to the application of the wrong procedure by the crew. The same may occur as a result of ill defined motion cueing in SD training.

Important is that one should limit the training program to flight profiles that fit to the motion envelope of the SD device, whether it is a simple or more complex motion based device. Motion cueing of simulators and SD devices is so important that it should be checked by experts (see also Section 3.4.4).

In short, for demonstrating SD more and more devices became available in recent years, even with man-in-the-loop capabilities. For ground-based in-the-loop SD training, i.e. flying into an SD illusion and adequate recovery thereafter, a lot of research needs to be accomplished. Consequently there remains a need for in-flight training about how to avoid SD and how to proceed once SD is encountered (Chapter 4).

Pilots should be made aware of the fact that many factors may facilitate the occurrence of SD. This comprises personality factors such as bravery, overconfidence, lack of discipline. Other examples are fatigue and stress. All such factors may affect the primary flying task. Gawron [37] provides many examples of how factors like personality, mental and physical state, experience, task and environment have their influence on SD. Although these factors are dealt with in the pilot training, they are not a primary part of the SD countermeasure training.

From the accident statistics we know that Type II SD accidents do occur, but that Type I accidents are more common. Apparently the pilots in those accidents aborted from their primary flying task for some reason. 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 [38]. The emphasis of the demonstration and training as described in Chapters 3 – 5 is 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 (see examples in Section 3.3 and 3.4).

3.2 ACADEMIC INSTRUCTION

3.2.1 Basics of SD Mechanism

The main cause of disorientation in flight is that the flight envelope is outside the daily posture and gait envelope inhibiting the human vestibular and kinesthetic receptors to provide 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. 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. Management of SD is an item more suitable for the advanced SD avoidance training. During basic SD demonstration, preventive measures should be dealt with as well in order to counterbalance the alarming effects SD hazards might have on student pilots: after all, SD illusions are the consequence of normal limitations of sensory function, which can be dealt with by good flying skills.

An outstanding formulation of the Didactic Syllabus of the SD Mechanisms was put together in the AGARD Working Group Report No. 625: 'Orientation/Disorientation Training of Flying Personnel', published in 1974 [1]. Braithwaite [2] elaborated on this syllabus and added some topics that became relevant for flying these years. It is this version which has been implemented in the present report, with some items in italics, added by the present Working Group. Dependent on the operating theater some issues may get more attention than others. This is also clear from the descriptions in Section 2.2.

3.2.2 The Didactic Syllabus of the SD Mechanisms

I) Introduction

  a) Definition of spatial disorientation (SD):

    i) A term used to describe a variety of incidents occurring in flight where the pilots fails to sense correctly the position, motion, or attitude of the aircraft or of himself within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical. In addition, errors in perception by the pilot of his position, motion, or attitude with respect to his aircraft, or of his own aircraft relative to other aircraft, can also be embraced within a broader definition of spatial disorientation in flight.

  b) Importance of correct perception of orientation in aircraft control.

  c) Spatial disorientation jeopardizes flight safety and mission effectiveness because of the following:

    i) Control based on false perception leads to loss of control and the orientation-error accident.

    ii) Conflicting orientation cues or abnormal sensations can heighten arousal and performance might be impaired.

  d) Aircrew need to know the following:

    i) Types of illusory perceptions occurring in flight.

    ii) Flight conditions and maneuvers likely to induce SD.

    iii) How to cope with disorientation if and when it occurs.

II) Mechanism of Orientation in Flight

  a) Dependent upon correct integration and interpretation (perception) of sensory information from the following:

    i) Eyes. Anatomy and physiology of the eye. Psychophysiology of vision. Focal and ambient vision. Depth perception.

    ii) Inner ear, especially vestibular part. Anatomy and physiology of the vestibular apparatus.

    iii) Other receptors in the skin, capsules, or joints and supporting tissues responding to the force environment.

  b) In the absence of veridical information provided by technological enhancements, vision is the only reliable channel of information using either:

    i) External visual cues, when flying in visual meteorological conditions (VMC).

    ii) Internal visual cues from instruments, when flying in instrument meteorological conditions (IMC).

  c) The aviator has to learn how to interpret cues. Interpretation of instrument cues is a more recently learned and more difficult task than interpreting external cues; proficiency has to be maintained by practice. Non-visual cues are frequently either inadequate or erroneous and do not allow the aviator to maintain a correct perception of aircraft orientation. They do, however, assist the pilot in sensing transient changes in aircraft attitude and motion and hence with visual cues can contribute to correct orientation in flight.

III) Mechanism of Disorientation in Flight

  a) Caused either by:

    i) Erroneous or inadequate sensory information transmitted to the brain.

ii) Erroneous or inadequate perception of sensory information transmitted to the brain.

b) Input error:

i) External visual:

- Cues inadequate as when flying at high altitude, at night, in cloud or other poor visibility conditions.
- Cues erroneous (i.e., departing from expectancy), e.g., sloping edge of a cloud bank or auroral display.

ii) Instruments:

- Inadequate sensitivity to displayed variable.
- Erroneous signal caused by malfunction or dynamic limitations.
- Vision impaired by nystagmus, glare, flash, etc.

iii) Vestibular and other receptors:

- Fail to indicate change in angular velocity or direction of gravity when stimulus below threshold.
- Semicircular canals do not signal sustained rotation.
- Erroneous signals are generated by linear and angular acceleration stimuli that differ in time course and/or intensity from those to which the body is normally exposed on the ground, e.g. post-rotary phenomena, somatogravic illusion, stimulation of semicircular canals by pressure change etc.

c) Central error:

i) Limitation of span of attention-coning of attention or fascination.

ii) False perception of cues because of:

- Error in expectancy (e.g. cloud leans, somatic autokinesis).
- Disturbed cerebral function consequent to:
  - High arousal.
  - Low arousal.
  - Alcohol and other drugs.
  - Hypoxia and hypocapnia.
  - Illness.
  - Fatigue.
- Dissociative sensations e.g. Break-off phenomenon.

IV) Commonly Described Illusions

a) False perception of attitude:

i) Leans (subthreshold acceleration).

ii) Somatogravic illusions – pitch-up on acceleration, pitch-down on deceleration, inversion during bunt (‘‘jet-upset’’ incidents).

iii) Misinterpretation of visual cues – false-horizon reference, ground-sky confusion, ‘‘lean-on-the-sun’’ illusion.

iv) Cross-coupled illusions.

v) G-excess illusions.

b) False perception of motion:

i) Somatogyral illusion – On recovery from prolonged angular motion.

ii) Subthreshold accelerations.

iii) Cross-coupled (Coriolis) stimulation.

iv) Pressure (alternobaric) vertigo.

v) Flicker vertigo and other illusory sensations induced by moving visual stimuli (waterfall effect in helicopters).

c) Dissociative sensations:

i) Break-off phenomenon.

ii) Magic-carpet illusion (flying).

iii) *Giant hand illusion.*

V) Causal Factors

a) Flight environment:

i) IMC – In particular on transfer from external visual to instrument cues.

ii) Night – Isolated light sources enhance probability of oculogravic, oculogyral, and autokinetic illusions, ground-sky confusion.

iii) High altitude – Dissociative sensations; false horizontal reference; also break off in helicopters at lower altitudes or on crossing escarpment.

iv) Flight over featureless terrain – False perception of height.

v) Hazard of SD during flight with night-vision devices (NVDs) – Image-intensifying night-vision goggles (NVG) and infrared systems.

b) Flight maneuvers:

i) Prolonged acceleration and deceleration in line of flight and catapult launches – Somatogravic and oculogravic illusions.

ii) Prolonged angular motion – Sustained motion not sensed, somatogyral illusions on recovery, no sensation of bank during coordinated turn, cross-coupled, and G-excess illusions if head movement made while turning.

iii) Subthreshold changes in attitude – The leans induced on recovery.

iv) Workload of flight maneuver – High arousal enhances disorientation and reduces the ability to resolve perceptual conflict.

v) Ascent or descent – Pressure vertigo.

vi) Cloud penetration – VMC/IMC transfer and attendant problems, especially when flying in formation or on breaking formation; Lean-on-the-sun illusion.

vii) Low-altitude hover – Dust (*brownout*), snow (*whiteout*), or water can obscure external cues (VMC/IMC transfer) – waterfall illusion.

c) Aircraft factors:
   i) Inadequate instruments.
   ii) Inoperative instruments.
   iii) Visibility of instruments.
   iv) Badly positioned displays and controls – Head movement required to see and operate.
   v) High angular rates of angular and linear acceleration, high maneuverability.
   vi) View from cockpit – Lack of visible aircraft structures enhances break off, poor visual frame of reference.

d) Aircrew factors:
   i) Flight experience.
   ii) Training, experience, and proficiency in instrument flying.
   iii) Currency and competency of flying practice.
   iv) Mental health – High arousal and anxiety increases susceptibility to disorientation.
   v) Physical health – Upper-respiratory-tract infection and pressure vertigo.
   vi) Alcohol and drugs – Impair mental function and ability to suppress nystagmus.

3.2.3 Organization of Academic Instruction

Although all the above mentioned issues can be dealt with in classroom lectures, it is obvious that the quality of instruction is enhanced when relevant parts are told in conjunction with demonstrations. This diminishes the length of each classroom instruction (see also Chapter 6: SD training optimization). Different lecturers for different issues also help to keep the interest of the student pilots.

3.3 DEMONSTRATION OF BASIC VISUAL AND VESTIBULAR ILLUSIONS

3.3.1 Demonstration Goal: Showing the Basic SD Mechanisms

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 (cf. Section 3.4). They are also told that later on in their pilot training they will be trained about how to deal with SD once encountered and how to avoid SD.

3.3.2 Organization

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. Some examples of illusions and how they can be evoked will be given below.

Examples of useful vestibular illusions by rotation about other axes than the yaw stimulus are incorporated as well.

The *visual* influence on orientation and motion perception is also very strong. There are numerous examples of visual stimuli that easily lead to misinterpretation of the visual surround (sloping runway, etc. for an overview of these illusions see [39]). Of interest for the basic SD demonstration is the contribution of moving visual stimuli on self-motion perception and the influence of visual frame information on the estimate of the direction of gravity. In showing these illusions one should always realize that vestibular stimulation is possible in the absence of visual stimuli, but that visual stimulation is always accompanied with vestibular stimulation (e.g. gravity). Students should understand that for normal everyday motion the vestibular and visual systems complement each other for correct motion perception (e.g. vestibular the high pass- and vision the low pass-filtered part). Consequently, students should understand that because of the insufficiency of vestibular signals alone, *misleading* visual stimuli easily lead to spatial disorientation. Along the same lines of reasoning, a sudden *absence of* visual stimuli (brown-out or white-out) may cause SD as well, since here too the vestibular system is unable to correctly sense the flight path.

The so-called *Coriolis effects* can demonstrate interesting beneficial and malicious interactions of the visual and vestibular sensors. When rotating with constant velocity with full view on the surround, head movements do not affect spatial orientation: One has still the perception of making head movements while turning around. However, closing the eyes and making the same head movements result in spectacular tumbling sensations. If the whole visual surround turns together with the subject, head movements have even stronger disorienting effects. The relationship is easily established with what would happen in-flight during a turn when moving the head looking inside the cockpit. The students understand quite well that the perceived aircraft motion will not be so overwhelming as on the rotating device (lower angular velocity) and will be interpreted therefore as a slight change of aircraft movement that has to be corrected for. It should also be pointed out that Coriolis effects in-flight are primarily disorienting and not nauseating.

The demonstration is for student pilots with hardly any flying experience and is therefore also suitable for non-pilot flying personnel (e.g. loadmasters, weapon instructors, flight surgeons, SAR, etc.). Group size should be small, which allows for an open, interactive atmosphere with sufficient room for questions and discussion. Moreover, small groups allow for each student to experience the demonstration him- or herself, and also to observe the stimulus and the response of fellow students. If all students experience the illusions at the same time without the opportunity to watch their fellow students (as in the MSDD), they should be informed accurately about the nature of the stimuli afterwards, otherwise the demonstrations are incomplete.

It is considered 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").

Demonstrations should be straightforward and understandable as well. The student will find it hard enough to match his or her sensation with what he observes that is going on. For this reason, we strongly recommend not to incorporate too complex stimuli. The use of correct stimuli gives students true understanding of the disorienting mechanisms, which is to be preferred over the mere demonstration of a variety of sensations that may occur during certain complex maneuvers.

Illusions should be demonstrated one by one and the underlying mechanisms explained.

Finally, it should be noted that for the basic SD demonstration one does not necessarily require a high-tech demonstrator device with a realistic cockpit. The fundamentals of SD phenomena can be adequately demonstrated using simple and straightforward research facilities of a vestibular laboratory (like a Barany-chair, see also [1]).

3.3.3 Equipment for Basic SD-Provocative Visual and Vestibular Illusions

Equipment for the basic SD course may be very simple. For demonstrating the vestibular illusions one needs a chair allowing concentric rotation (subject in centre of rotation, allowing demonstration of somatogyral illusions) and eccentric rotation (subject sitting at a certain radius, allowing sustained linear accelerations for demonstrating the somatogravic illusions), or one needs two chairs, one for each application. The chairs need to be servo-controlled for smooth motion patterns, and to have minimal vibration and noise levels. Acceleration levels should preferably range from about 0.5˚/s² to 90˚/s² with velocities up to 180˚/s in either direction. One should assure that the chairs are man-rated. Although interesting vestibular illusions may be demonstrated with devices which allow rotation about a second axis, e.g. the roll axis, these illusions are not necessary to illustrate the basic vestibular SD evoking mechanisms.

For demonstration of visual illusions simple slides may be used for demonstration of the rod-and-frame effect and other well-known visual illusions. For demonstrating the perceptual consequences of moving visual stimuli (vection), simple PC-based programs may be helpful, or simple rotating domes with vertical black and white stripes (each stripe about 7˚ of visual angle) covering the whole field of view. Velocity of the optokinetic pattern should vary up to 90˚/s in either direction. Projection of a light spot for demonstrating the autokinetic effect is easily accomplished with a laser pointer attached near the head.

The room, in which these demonstrations are given, should be light-tight. Precautions should be taken that student pilots who are just observing their colleague on the chair, cannot enter the perimeter of the chair.

Demonstration with these devices is very cost-effective. One should realize, however, that refresher training with these devices does not make sense: For continuation training students should be in-the-loop, which asks for more complex motion devices. Complex motion systems like ETC's Gyrolab or AMST's Desdemona also allow for this basic training because of their eccentric rotation capabilities and fully gimballed cockpits, although their power should be found in the advanced SD avoidance training, the refresher course. The smaller types of SD trainers like ETC's Gyro IPT or AMST's Airfox have the yaw rotation facility, but lack the eccentric rotation: they simulate somatogravic illusions by tilt coordination. This last procedure requires explanation for those who are observing the demonstration. Demonstration of somatogravic illusions with centrifuges with free swinging gondolas is possible, but requires a lot of explanation to both test subject and observer subjects (see also Section 3.4.3.6). The same holds for demonstration of this illusion with the MSDD.

Visual stimulus equipment like servo-controlled optokinetic drums and tilting rooms, or sophisticated visual 3D cave projection systems are also suitable systems to demonstrate the powerful basic visual motion illusions. Just as with the complex motion systems, the organisation of this part of the course determines the use of simple or complex devices. Whether these demonstrations are desirable or essential in the SD training program depends on many factors (see also Chapter 6).

3.3.4 Examples of Basic SD-Provocative Visual/Vestibular Illusions

Some examples of demonstrations are:

3.3.4.1 Somatogyral and Oculogyral Illusion, Autokinetic Effect
Device: Rotating Chair, Yaw Mode

With *somatogyral illusion* reference is made to the false sensation of rotation or absence of rotation which results from misperceiving the magnitude and direction of an actual rotation. This characteristic of the semicircular canal response is easily experienced during rotation about a vertical axis (yaw axis rotation). Efficient is a trapezoidal velocity profile with a 90º/s² acceleration up to an angular velocity of 90º/s, which is maintained for 90s and followed by a deceleration of 90º/s². The subject under the hood verbally reports the perceived angular motion. Eventually the subject may also indicate the change in position in time by pointing a joystick in a fixed heading (like a compass needle). For the other student observers along the sideline this clearly shows that the turning sensation fades away during constant velocity rotation and starts again, but now in the opposite direction, when the chair stops (somatogyral illusions). Fixation on a LED display which is attached to the chair under the hood may induce the oculogyral illusion during the postrotatory sensation. With *oculogyral illusion* reference is made to the illusory displacement and/or rotation of a small, head-fixed spot of light.

The lack of response to subthreshold accelerations ($< 0.5°/s^2$) is also a very informative somatogyral illusion, especially for the observer students: The subject should be instructed to open his eyes after a while to see with his own eyes what is really happening. Fixation on the LED display without any acceleration may induce the autokinetic effect.

An efficient profile for showing the adverse effects of (horizontal) nystagmus on instrument reading is a sinusoidal acceleration profile with a frequency of 0.033Hz and maximum speed of 180º/s. The hooded student is asked to read a matrix of numbers on a display straight-ahead.

3.3.4.2 Somatogravic Illusion, Somatogyral Illusion, Roll Vection
Device: Rotating Chair, Eccentric Yaw Mode

The somatogravic effect is generated with a rotating chair, with the chair positioned at least 0.5m off-center. With a radius of 0.5m a preferable profile is to increase the angular velocity gradually from 0 – 180º/s, producing a lateral acceleration of about $0.8 m/s^2$. Centrifugation in the dark typically produces a sensation of up to 30º static outward tilt (somatogravic illusion). This demonstration becomes even more impressive when a dome is mounted on the chair onto which a random dot pattern is projected that rotates on the pilot's roll axis. This optokinetic roll-stimulus demonstrates by itself already a disorienting visual-vestibular interaction in that the subject reports a percept of continuous body roll without ever reaching upside-down: mostly a body tilt is experienced of about 10º. The combination of centrifugation and visual roll motion, however, effectively produces a sensation of full head-over-heels rotation as in an aileron roll in many subjects [40]. If the subject faces inward, exposed to an x-axis acceleration, a pitch-up sensation may be obtained under these conditions. This element convincingly shows the aviators that sensations that are completely different from the actual stimulus are easy to obtain. Moreover, comparison of the individual time histories and magnitudes of the response of the student pilots shows that different people may assign different relative weightings to the visual and vestibular signals, but that – in general – the response is the same.

3.3.4.3 Somatogravic Illusion, Somatogyral Illusion
Device: Rotating Chair, Roll Mode

With a rotating chair in the roll mode, two effects can be demonstrated. First, students estimate the angle of perceived body tilt (attitude) while the chair is put in different static orientations. This shows how people overestimate their body tilt in the dark and how inaccurate the biological attitude indicators are.

Typically, in this demonstration subjects overestimate their tilt angle with a factor two, and it is not uncommon that subjects feel almost inverted at 90º of tilt to one side. The inability to estimate tilt angles correctly is very surprising to experienced pilots, who are supposed to fly with a precision within degrees. This way they learn that the correct sensor for this precision is outside the body, i.e. the flight instruments. When the chair is positioned upright again after several minutes of body tilt to the same side, there remains a feeling of 5 – 10º tilt in the opposite direction. This is an example of the "leans".

The second effect demonstrated in this mode is the "ferriswheel illusion". Constant rotation about the horizontal roll axis (90º/s) leads to a series of sensations, where the aviator at the end no longer feels rotation but, instead, an alternating horizontal and vertical translation. Here too it is imperative that the subject who undergoes this demonstration is also able to observe the demonstration with a fellow-student. This illusion nicely contrasts with the sensation during eccentric yaw motion where aviators perceived continuous roll motion during linear acceleration, while during this actual roll motion they perceive linear acceleration.

3.3.4.4 Visual-Vestibular Interaction in Coriolis Effects
Device: Rotating Chair, Yaw Mode

The chair is brought in constant yaw rotation and subjects make head tilts on demand. By comparing the effects with eyes open and eyes closed, students experience that the angular chair motion and the head movements are accurately perceived with a clear view on stable surroundings, but that the sensations may soon become disorienting (tumbling sensations), or even discomforting with the eyes closed or under the hood [41]. Angular velocity during the demonstration should be kept low in order to avoid problems with motion sickness (<90º/s), but high enough to demonstrate the Coriolis Effect (>60º/s).

3.3.4.5 Visual Frame (Rod-and-Frame Effect), Somatogravic Illusion, Oculogravic Illusion
Device: Tilting Room

In a tilting room the effect of a tilting visual surround on posture and the percept of verticality (visual leans) is demonstrated [42]. One pilot is standing on a fixed platform (eventually covered with foam rubber) inside the room, trying to keep his balance, while the room has a static tilt angle (10º) or tilts sinusoidally (amplitude 10º, frequency < 0.2Hz). The subject verbally reports on the apparent deviation of the subjective vertical. His or her postural behavior may be visualized by means of posturography. The message of this exercise is that it is impossible for them to choose the correct information modality: Despite the fact that they know that they are mislead by the visual information, their postural sway is clearly influenced by the movement of the room. This illustrates that they have to depend on the flight instruments.

3.3.4.6 Circular Vection, Pseudo-Coriolis Effects
Device: Optokinetic Drum

If the subject opens his eyes when the visual surround (the optokinetic drum) moves around him (60º/s), the subject first experiences object motion, but soon he perceives angular self-motion (circular vection) as well into the opposite direction as the surround motion, resulting after a few seconds in a full self-motion experience including a percept of a stationary drum. Tilt of the head results in tumbling sensations, similar to Coriolis effects: these are called Pseudo-Coriolis effects (cf. Coriolis effects in 3.3.4.4 where head movements during rotation with the eyes open do not result in tumbling sensations).

3.4 GROUND-BASED TRAINING OF IN-FLIGHT SD ILLUSIONS

3.4.1 Goal of Ground-Based Training of In-Flight Illusions

The goal of the demonstrations dealt with in this section is to demonstrate and explain on the ground the SD *in-flight* illusions. This part is a logical follow-up of the demonstration of basic SD mechanisms (Section 3.3). The demonstration is suitable for student pilots with hardly any flying experience. Since this part is primarily demonstration and explanation of various illusions, they are also told that later on in their pilot training they will be trained about how to deal with SD once encountered and how to avoid SD. For experienced pilots (refresher training) part of the profiles can be flown in the loop, with practice of recovery procedures once SD is encountered.

3.4.2 Organization

Since the ground-based demonstrations concern *in-flight* SD illusions, the simple demonstration devices from Section 3.3 are not sufficient anymore. For this purpose special motion based flight simulators have been developed of different levels of complexity. These simulators have a cockpit, out-the-window visuals and a motion base (Section 3.4.3). Most of these devices allow for closed-loop control, but they also allow for open loop reproduction of an SD provocative flight profile. For the demonstrations discussed in this section, both control modes are used to provoke the illusion: The goal is creating the illusory percept and the understanding of why it happened. How to prevent and recover from the SD incident has to be discussed, and, if possible also practised. This requests capabilities from the SD device in terms of replay modes, control by the IP, and so on (Section 3.4.3). Since these in-flight SD illusions are demonstrated in a simulator, the involved motion cueing mechanisms are often not obvious to the student or the observers, because the simulator motion is clearly different from the aircraft motion. So the instructor should have sufficient understanding of the involved motion cueing to be able to explain the student's motion perception and/or SD illusion. The principles of motion cueing are discussed in Section 3.4.3.6. In Section 3.4.4 a variety of examples are discussed, but the choice of these examples depend on the training objectives for the pilot in his operational theater. This ground-based demonstration/training of in-flight SD illusions should preferably take place in conjunction with the basic SD illusions (Section 3.3), since the basic SD illusions highlight the mechanisms involved in the in-flight SD illusions. For certain aspects of SD full flight simulators are applied as well (Section 3.5).

3.4.3 Equipment for Demonstrating In-Flight Illusions on the Ground

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; 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 Section 3.5), but they fall short in simulating SD if sustained accelerations are involved.

It is obvious that the potential to generate (more) illusions convincingly increases with better visuals and more elaborate motion platforms, but this will be in vain if the motion cueing and/or the profile design are inappropriate to induce SD. Therefore the use of a categorization of special SD devices is questionable. Nevertheless, in the AIR STD 61/117/14 [31], which is proposed as an annex in the draft version of Edition 8 of STANAG 3114, a classification of SD trainers is presented (Table 3.1). This classification is based primarily on the principles of the motion platforms rather than the technical specifications or the motion cueing requirements.

Table 3.1: Categorisation 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 motion cueing involved in the various SD devices differs for each illusion to be demonstrated and often includes special effects implemented by the manufacturer of the device. Moreover, training instructors may tune the parameter settings based on their own professional experience. Motion cueing aspects are discussed in more detail in Section 3.4.3.6.

According to Braithwaite et al. [2] issues to be considered in selecting a SD device are:

1) The ability to demonstrate common illusions;
2) The reproducibility and consistency of an illusion;
3) The instructor-pilot interaction;
4) The training capability; and
5) The costs of devices.

Other contributing factors in the choice of an SD device are the task-related SD issues for the relevant pilots (jet pilots flying high or helicopter pilots flying nap of the earth need other SD issues to be discussed), the number of pilot trainings, other tasks on the device like research, and so on.

Obviously, many factors play a role. The equipment related issues will be discussed in more detail in the following sections.

3.4.3.1 Fundamental Makeup of a Ground-Based SD Trainer

There are fundamentally three separate, but integral components to all ground-based SD trainers - the cab, the motion platform, and the user interface, all of equal importance. According to the logical order from a pilot's perspective, the discussion will start with the cockpits first (often referred to as the cab), followed by the motion system, and finishes with the ever complicated but critical workstations (the graphical user interface). This last feature allows the instructor to create specific illusions while controlling the visual and motion.

3.4.3.2 Cockpit or Cab

The cockpit is probably the most important physical characteristic of a ground-based SD trainer. It may not be the component that makes the SD illusions happen but it is the feature that everyone sees and it often makes the first critical impression of those who ride it. If it doesn't look like an aircraft cockpit, it cannot perform like an aircraft – at least that's the commonly held perception by many. Remember, there are many other features considered important to adding realism, but the cockpit is the most obvious, and often can make or break the pilot's opinion of the device. Experience has shown that the pilot must be comfortable when sitting in the seat, and he or she should be able to enter and exit the cab without a lot of physical exertion.

3.4.3.3 Visual Out-The-Window Scene (OTW Visuals)

The visuals should be of a high resolution and at least 120 degrees of horizontal viewing surface and about 40 degrees of vertical surface. Rendering of the visual scene must be fast enough so that the virtual world does not "build" as the pilot flies over the landscape with sufficient resolution. However, resolution is not enough. Features are critical to the creation of many of the visual illusions. Some examples of in-flight visual SD illusions, which should be demonstrable:

- Aubert (A) Effect — Tendency to view a vertical line as tilted away from the direction of self tilt, which happens at large tilt angles (>60°); The A-effect is the opposite of the Mueller or E-effect.
- Autokinetic Effect — Illusion that a small stationary spot in an otherwise darkened environment begins to move, usually after a period of 10 s or more of fixation on it.
- Black-hole Approach — Landing approach to a runway at night, characterized by a lower-than-perceived glide slope, when the terrain surrounding the

	runway is not highly visible; the low-approach tendency is enhanced when additional visual illusions caused by sloping or narrow runways or fog are present.
• Brownout	Visual condition that occurs when blowing sand, dust, and other ground particles reduces low-level flying visibility. (cf. Whiteout)
• False Horizon Illusion	Illusion of accepting the false horizon as the real horizon.
• Flying-carpet Illusion	Sensation of flying on top of the aircraft without its frame, as is most likely to be experienced in aircraft like the F-16 with its large glass canopies and restricted views of the terrain.
• Inversion Illusion	Illusion in which pilots at least temporarily feel as though they are inverted to the earth. This may be caused by visual factors (brighter water than sky).
• Mueller (E) Effect	Tendency to view a vertical line as tilted toward the direction of own tilt, which happens at moderate tilt angles (<30°). This effect is the opposite of the A-effect.
• Rod-and-Frame Illusion	Illusion that a small vertical rod is displaced opposite to the tilt of a larger frame.
• Variation of Runway Width	Illusion of flying too high when flying over a narrower than normal runway.
• Variation of Runway Slope	Illusion of flying too high when flying over an up-sloping runway.
• Vection	Illusion of self-motion, opposite to a moving visual scene, induced in a stationary observer mostly with a wide FOV scene.
• Whiteout	Visual condition that occurs when blowing snow reduces low-level flying visibility. See also Brownout.

The cockpit should be light tight. The ability to make the interior of the cockpit completely dark allows for the creation of the visual illusion known as autokinesis. To create this apparent visual motion, the cockpit must not have any stray light sources, which destroy the motion sensation.

Another feature of the visual system is collimation. Collimation aligns the optical path so that the out-the-window scene is located at optical infinity. Although many have suggested collimation as a necessity feature for producing visual realism, some of the more recent flat panel, high-resolution displays seem to generate an appearance of realistic visual conditions. One should compare the pros and cons of this particular feature before deciding on whether or not to include it as a visual requirement.

Perhaps the best static visual simulators for flight training are the domes. These spheres provide almost unlimited FOV. The stationary cockpit sits near the centre of the sphere and computer-generated imagery is projected onto the surface of the sphere, or dome. In order to give the illusion of motion, the real image that is projected on the dome is at a distance where the eyes accommodate to infinity; the domes are usually 20 – 40 feet in diameter so that the image is at least 10 feet away from the observer. Many smaller, static, visual systems use virtual images that are developed by observing a TV or screen through optics that collimate the image and present it at infinity (greater than 20 feet away). Many pilots throughout the world have been trained in these devices. The main drawback is that trainees can develop simulator sickness, which is characterized by nausea and sometimes flashbacks. This may occur because visual cues are not reinforced with motion cues in static simulators according to some theories. SD training in a device without motion cues can result in negative transfer of training if critical motion cues are absent.

3.4.3.4 Instruments

The head-down instruments should mimic the aircraft cockpit that is most often used by the pilots who receive the SD training. With up-front planning, several different cockpits can be pre-programmed so that the user is able to change out the cockpit to resemble a different cockpit in a matter of minutes. The more complicated the instrumentation and the necessity to define the controls needed to fly the simulator, the longer it may take to reconfigure the cockpit.

The instruments should reflect the correct size, colouring and mechanization. All of these features reflect the realism of the cockpit, which will feed into the perceived environment when the pilots fly the device. Interaction with each of the instruments is a desirable feature but appears to drive up the basic cost. This feature is needed for some of the Type I SD conditions.

Lighting within the cab should include floodlights, instrument lights, and warning-caution lights.

It must be decided whether to have a single seat configuration or a dual seat configuration. In the fighter mode of operation, a single seat is the standard with another seat at the console, while with the cargo and other multi-seat aircraft, side-by-side configuration should be considered, especially when in need of a device for crew resource management training.

3.4.3.5 Motion Platform

The choice for the motion platform depends primarily on the training goal. One should determine first which illusions are needed for the pilots under training. Based on the motion profiles involved in these illusions an analysis should be made to determine the required degrees of freedom of the motion platform and the required motion cueing algorithms (see Section 3.4.3.6), which determine together the simulator motion space and consequently the lay-out of the motion platform. If the result of the analysis shows that ground-based simulation is impossible, one should look for in-flight demonstration and training options.

3.4.3.6 Motion Cueing Requirements

The disorientation training devices are used to make pilot trainees aware of the phenomenon and safety risk of disorientation and/or train experienced pilots to avoid disorientation. For general pilot training issues, Flight Training Devices (FTD) of various levels and fidelity are used for training. From the FTDs' for transport pilot training, only the Full Flight Simulator (FFS) has outside visual and motion systems from which the Level D FFS has the highest fidelity.

The disorientation device and the FFS correspond with each other in the use of an outside visual system and a motion system to present the pilot trainee with motion cues representing the actual motions of the simulated aircraft. Since the motion systems of both training means have a limited motion space, they are never capable to simulate the aircraft motions one by one. To compensate for that, motion cueing algorithms are applied to transform the aircraft motions to simulator motions [43]. Given the more than thirty years experience with motion cueing for pilot training, it speaks for itself to compare the generation of motion cues for disorientation avoidance training and normal flight training.

In civil transport pilot training, full flight simulators are mandatory for type conversion, recurrent training and proficiency checks. The hexapod motion system is the standard. Although in the regulations quite some technical details are laid down, even after more then thirty years of experience, no requirements for motion cueing are prescribed [44,45]. This is a result of the lack of understanding of pilot's motion perception and the influence of motion on his control behaviour.

So far, the adjustment of motion cueing algorithms is based on the subjective judgement of experienced (test) pilots. Since the introduction of the hexapod motion system a wide range of experience has been obtained and the quality of motion cueing has been improved over the years.

To avoid this subjective method in the future, initiatives has been taken by working groups of the AIAA (American Institute of Aeronautics and Astronautics), the RAeS (Royal Aeronautical Society) and research institutes to develop objective methods to adjust and validate motion cueing algorithms [46,47]. Also, methods to determine simulator fidelity are under development [48,49,50,51].

Just as for transport aircraft simulators, the manufacturer of the SD Demonstrator or Trainer will provide the motion cueing algorithm for the SD training. They are assumed to have the experience and competence to develop and adjust the motion cueing algorithm for the specific training device and its application. For the success of SD avoidance training it is vital that the briefings before and after the training session correspond accurately with the presented demonstrations and that the instructor is able to understand and explain the differences between simulated and real SD. So, the training organization operating the SD Demonstrator/Trainer must have insight into the principles of the motion cueing algorithm and be able to readjust the parameters of the algorithm to keep pace with the development of the SD training program or must have the support of the manufacturer or specialized institute.

The goal of using a motion system for disorientation avoidance training is quite different from the application for flight training, despite the fact that in both cases simulator motion is applied to support pilot's perception of the aircraft motions in a synthetic environment. The typical simulation problem is that the motion space of a simulator can never match the motion space in real flight. That means that pilot's vestibular stimulation in any simulator is never equal to that in real flight. That limits the realistic application of motion simulation for disorientation avoidance training to those manoeuvres where pilot's motion perception can be matched to that in real flight.

In normal flight training the tasks to manage flight and control the aircraft are trained simultaneously, with emphasis on the management task. In SD avoidance training attention is much more focused on pilot's motion perception and flight safety by inducing typical SD incidents. In that case motion perception has to be treated more subtle than during normal flight training. This is, among others, accomplished by applying mechanically more complicated motion systems (Diso Airfox, Gyrolab or Desdemona), which provide the required additional motion space and allow more complex SD manoeuvres to be simulated (Figure 3.1).

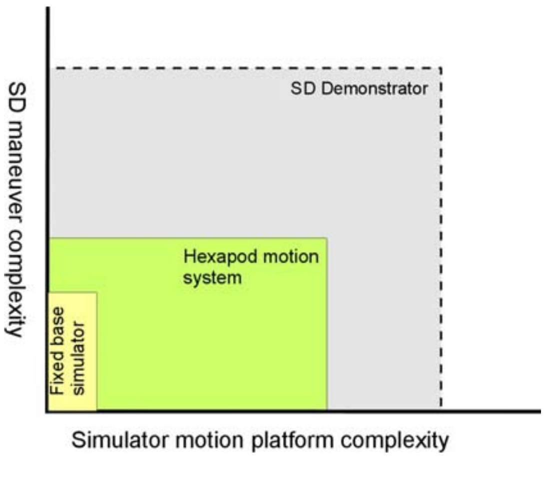

Figure 3.1: Motion System Complexity Enables More Complex SD Manoeuvres to be Simulated.

Depending on the SD Training Device, each SD incident may require a special motion cueing algorithm to optimize the training.

During the last decades mathematical models describing motion perception and pilot's control behaviour were developed and evaluated. These models are used to analyze and optimize the motion system configurations and motion cueing algorithms for flight simulation. As shown in Figure 3.2 differences in perceived motion due to the simulation process (motion system characteristics, simulation time delays, motion cueing algorithm) may be analyzed, providing insight into the shortcomings of the simulation process and its fidelity. So, when all characteristics of the motion cueing system of an SD Trainer are known an analysis can be performed for each SD inducing manoeuvre. Such an analysis provides information on the fidelity of the simulation of the SD inducing manoeuvre at a particular SD Trainer.

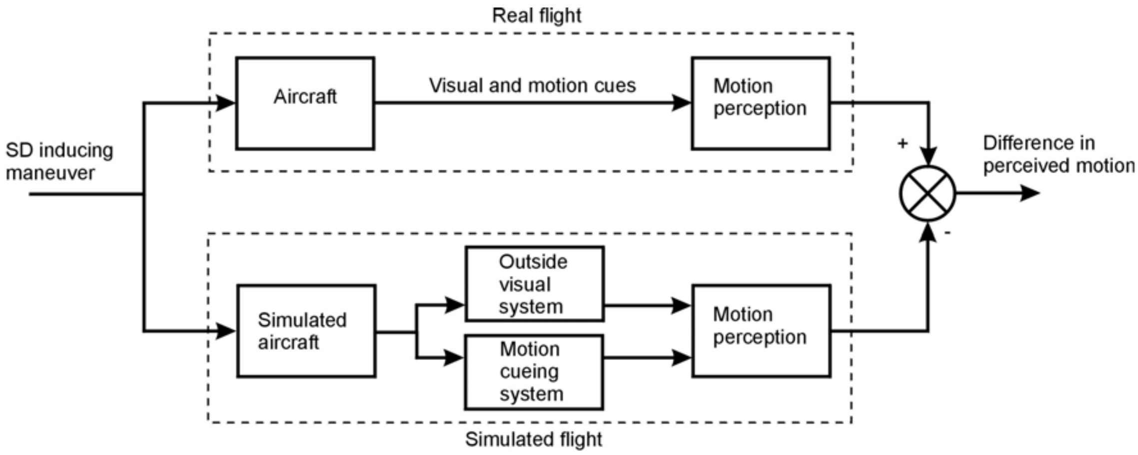

Figure 3.2: Scheme for the Analysis of Perceived Motion in Real and Simulated Flight.

A possible next step is the optimization of the motion cueing algorithm for the simulation of each SD inducing manoeuvre in the SD Trainer.

In conclusion:

- For optimal use of disorientation-training devices motion cueing algorithms have to be designed to optimize the use of the special motion system for the benefit of the disorientation training.
- The SD instructor has to be able to understand and explain the differences between real and simulated SD incidents.
- Complex motion systems for disorientation training have to be chosen based on the training objective and the ability to simulate the requested SD incidents.

3.4.3.7 Work Station

Creating these visual conditions is dependent upon the nature of the user interface, and this will be discussed in the user interface section, but in this section some of the fundamental conditions about the display and instrumentation are identified.

3.4.3.7.1 Necessary Capabilities

- Fly and Demonstrate from Console;
- Freeze/Blank Instruments;
- Freeze Flight and Change Visual Conditions (simultaneously);
- Control basic SD motion over flight simulation movement (program) with conditional events;
- Conditional Event Visual System;
- Playback; and

- Display Performance (e.g., ILS, the Instrument Landing System).

3.4.3.7.2 Nice to have Capabilities

- Generate Formation;
- Integrate NVG (cab feature);
- Instructor fly lead;
- Interact with other systems; and
- Helmet-mounted displays.

3.4.3.7.3 Reproducibility (95% Reproducibility)

- False Pitch (vestibular);
- False Bank (vestibular and visual);
- False Yaw (vestibular);
- Landing (visual/vestibular); and
- Unusual Attitude Recovery Practices.

3.4.3.7.4 Practices (One for the Novice and One for the Expert)

- Basic Sortie;
- Takeoff;
- Departure;
- Navigation;
- Approach and Landing;
- Advanced Sortie;
- Takeoff (formation – radar);
- Departure;
- Navigation;
- Mission Requirement (air refuelling, target identification);
- RTB and Landing; and
- Sensor technology (IR, MMR).

3.4.3.8 Future Ground-Based Simulators for SD Training

What is needed is a fleet of trainers that can be accessible to NATO aircrew worldwide. Although it is often argued that SD training should not be too expensive, one should realize that the costs involved in SD accidents are very high (see Chapter 1). Current state-of-the-art SD trainers are approaching $ 4M each. Most Air Forces cannot afford these devices. However, by sharing facilities the costs of the training can be reduced and these devices come within reach. The attributes of future SD ground-based training devices include:

- Motion system (on some devices);
- Wide angle visual display system;

- Computer Generated Imagery with easy-to-use software; and
- Helmet mounted systems interfaces (NVG and HMD emulations).

3.4.4 Examples of Ground-Based Demonstrations of In-Flight Illusions (AIR STD 61/117/14)

In the draft version of Edition 8 of the STANAG 3114 it is recommended that for the practical instruction of Spatial Disorientation the experience of spatial disorientation should comply with the AIR STD 61/117/14 [31] and be related to the aircraft flown by the student. This air standard lists a series of common in-flight SD illusions, which is shown in Table 3.2. Also indicated in Table 3.2 is the type of the illusion (visual, vestibular or visual-vestibular), the demonstrating device category (according to Table 3.1), and which illusions are particularly suitable for fixed-wing and/or for rotary-wing pilots.

Table 3.2: The Illusions for Fixed- and Rotary-wing SD Demonstration as Presented in AIR STD 61/117/14

Illusion / limitation of senses	Type	Demonstration Device Category	Fixed-Wing	Rotary-Wing
The Leans	Vestibular	2, 3, 4	√	√
Spin Recovery (Somatogyral)	Vestibular	2, 3, 4	√	√
Graveyard Spiral	Vestibular	4	√	
Oculogyral	Visual-Vestibular	1, 2, 3, 4	√	√
Somatogravic	Vestibular	2, 3, 4	√	
Oculogravic	Visual-Vestibular	3, 4	√	
Coriolis	Vestibular	1, 2, 3, 4	√	√
G- Excess	Vestibular	4	√	
Autokinesis	Visual	2, 3, 4	√	√
Size constancy (Runway width)	Visual	2, 3, 4	√	√
Shape constancy (Runway upslope)	Visual	2, 3, 4	√	√
Black-hole landing	Visual	2, 3, 4	√	
Vection illusion	Visual	2, 3, 4		√
False sensation of rotation	Vestibular	1, 2, 3, 4	√	√

The demonstration devices of categories 2, 3 and 4 have often pilot-in-the-loop capabilities and the manufacturers supply the various illusions with special motion cueing effects. They use not a general cueing principle applicable to all illusions, but adapt the motion cueing to each single illusion to guarantee that the illusion is perceived as such indeed. The more sophisticated the demonstration device (categories 3 and 4) the closer the creation of the illusion mimics the underlying physiological mechanism. It is especially for devices from the second category that creation of the vestibular illusion is accomplished by artificial motion simulation. This implies that the illusion will be experienced by the student inside indeed, but it is mandatory that a thorough explanation about the underlying physiological mechanisms of the illusion in real flight will be given during the demonstration or afterwards. The more so since manufacturers often use scenarios in which (partial) instrument failure is simulated and stressors are applied in the flying task. This facilitates the creation of the illusion, but leaves the pilot often unaware of what really caused the illusion. Fellow student pilots should not watch the demonstration, since from the motion of the device alone they cannot derive the underlying mechanism of the illusion. If they are allowed to watch, they should get sufficient explanation. In the next paragraph an example is presented of how different manufacturers use different devices and techniques to demonstrate the ‘Leans’ illusion.

3.4.4.1 The Leans

The Leans is the feeling of being banked when the aircraft is actually upright and level. It is one of the most common illusions. The illusion is reported to occur after levelling out from a prolonged turn (gravito-inertial forces) when flying by instruments. The illusion may last for minutes[1].

3.4.4.1.1 The Leans as Produced in the Gyro IPT II by ETC (Environmental Tectonics Corp., Southampton, PA)

For the Leans demonstration ETC uses the Gyro IPT (Integrated Physiological Trainer) II. This device comes standard with a cockpit that resembles a single engine turboprop training aircraft (i.e. PC-9 / T-6A) and wide field of view, OTW visuals. According to the specifications, the motion platform has 6 (4+2) DoFs: The structure is built on the yaw axis, which axis allows for continuous rotation simultaneously with pitch, roll and heave. The student pilot controls the aircraft during the whole demonstration. The demonstration itself is completely automated, but an instructor is present to answer questions. The in red indicated motion profiles are superposed on the pilot induced simulator motion.

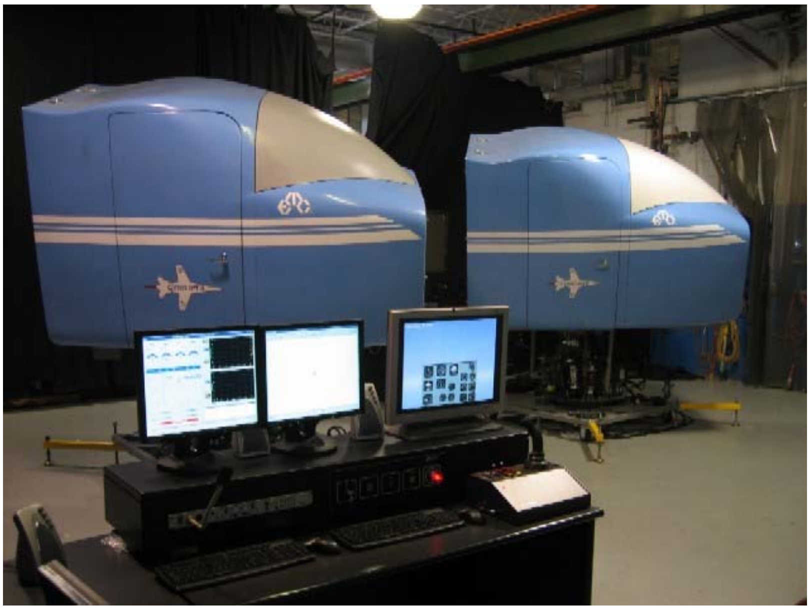

Figure 3.3: Gyro IPT II (ETC, Southampton, PA).

Initial conditions:	Altitude: 8,000 ft. Airspeed: 200 Knots. Heading: 300°. Time of Day: night. Clouds: intermittent.

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[1] The TG appreciates that Environmental Tectonics Corp. (Southampton, PA) and AMST Systemtechnik (Ranshofen, Austria) granted permission to describe in detail their procedure and motion cueing effects to produce The Leans.

Time: 0 Start of demonstration.

Time: 2 Narrator: "You and your instructor are en route to the practice area for a night Basic Fighter Maneuver exercise."

Time: 29 Instructor: "Make a right 45º banked turn to heading 270 for the practice range."

Time: 35 and at > 5° aircraft bank angle:

Gyro IPT II: Rolls at supra-threshold rate to a 10° right tilt angle. Simultaneously GYRO IPT II pitches subliminally to 10° nose up and accelerates subliminally to a yaw rotation of 12°/s to the right.

Time: 85 and at heading greater than 260°:

Instructor: "Roll to wings level and maintain your heading".

Time: 88 and at < 40° aircraft bank angle:

Gyro IPT II: Rolls back to upright position in about 3 seconds and simultaneously pitches to level, also in about 3 seconds. Simultaneously, yaw motion slows down to a full stop in about 4 seconds.

Time: 95 Attitude, heading indicators freeze.

Time: 105 Attitude, heading indicators unfreeze.

Time: 110 Narrator: "You have just experienced the leans. This common illusion occurs when the pilot enters a turn slowly or when the pilot executes a prolonged turn where the acceleration has become a constant velocity. In either case the semicircular canals in the vestibular system don't accurately register the turn, but do register the roll out. The result is the false sensation of being in a banked turn when you are actually straight and level."

Time: 140 Narrator: "The Leans is a common illusion which can be easily controlled. For this and for many other illusions, the most effective way to recover is to get on the instruments and make them read right until the illusion has subsided."

Time: 155 Narrator: "This sensation will subside shortly. If you experience the leans in flight, get on your instruments."

Time: 175 End of demonstration.

3.4.4.1.2 The Leans as Produced in the Airfox by AMST (Ranshofen, Austria)

For the Leans demonstration AMST uses the Airfox. This device has a generic fighter cockpit with OTW visuals. The motion platform has 6 DoFs. Six DoFs are in a standard hexapod configuration, and an additional yaw rotation platform allowing unlimited yaw rotation, is positioned on top of the hexapod platform. The cockpit is positioned on top of this yaw rotation platform. The demonstration requires an Instructor Pilot (IP) at the desk. The Student Pilot (SP) has active control of the aircraft (the Airfox): The yaw rotation platform is not active, the hexapod platform functions with (almost) standard washout algorithms. In red a description of how the Airfox is actually moving to produce the Leans.

Training Mode	Leans active
HUD (Cockpit Instrumentation)	OFF
Step 5 (Cockpit Instrumentation)	ADI, Directional Gyro **off**
Step 7 (Cockpit Instrumentation)	ADI, Directional Gyro **on**
Init Condition	F16 flying IMC at 3000ft, 300kts, PWR 25%, HDG 360°
Frequency	Kalamata APP, 120.75
Duration	4 min
Objective	Student Pilot (SP) feels the leaning sensation after rolling out quickly from a steady turn in IFR conditions. The sensation disappears with continued flying according to the instruments.

Figure 3.4: Airfox Diso (AMST, Ranshofen, Austria).

Procedure

(1) SP SP gets control.

(2) IP **"Iceman, this is Kalamata Approach: turn right on to HDG 180° with max. bank 30°, maintain altitude, report steady 180°".**

(3) SP "Kalamata Approach, Iceman is turning right to 180°, maintaining alt, reporting 180°".

(4) SP Turns slowly right, using 30° bank.

Airfox since the onset was slow, the excursions of the motion base (yaw right, roll tilt right) are very small and the washout filters bring the Airfox back to the upright position.

(5) IP Reaching 150°: **ADI, Directional Gyro – OFF.**

(6) IP **"Continue turn with 30° bank according your sensations".**

(7) SP "Roger".

(8) IP Reaching 170°: **ADI, Directional Gyro ON.**

(9) IP **"Fly straight and level according your instruments".**

(10) SP Rolls out quickly at 180° and should feel a strong leaning sensation slowly decreasing.

Airfox since the maneuver is faster, the excursions of the motion base (yaw left, roll tilt left) are more pronounced, but the washout filter neutralises the yaw excursions quickly, whereas the roll tilt remains longer due to special filter parameter settings.

(11) IP **"Continue flying straight and level according to your instruments, the sensation will become normal again".**

(12) SP Will feel a reduced leaning sensation.

Airfox the roll tilt to the left has gradually decreased.

(13) IP **Explains the effects of the Leans**. "The Leans is an error in perception of the roll attitude. The bank usually is caused by a wing drop of as little as 0.2° to 8.0°/s or less. Because the change in attitude is so gradual, the semicircular canal fluid moves very slowly, and the change is imperceptible to the aviator (sub-threshold). The perception is that of a change in attitude, falsely interpreting the leveling of the wings to a change in aircraft attitude to the opposite direction. If the aviator then relies on his instruments for proper attitude, he will tend to "lean" his body in the same direction as the original bank. The erroneous sensation normally disappears in a few minutes, but has known to be as long as 30 to 60 minutes. The Leans is most frequently reported associated with recovery from a co-ordinated turn to level flight when flying by instruments, as in this demonstration."

(14) IP Stop and end of profile.

3.4.4.1.3 Discussion

Both demonstrations induce the Leans sensation, but the methods are quite different: With the Gyro IPT II the illusion is induced by a cross-coupled Coriolis effect due to the cockpit levelling during continuing yaw motion. The Airfox parameter settings cause a real tilt with conflicting instrument readings. It is clear that there is no need to tell the student pilot how the illusion was induced in the simulator, but explaining under which conditions he may encounter the illusion in real flight and what the underlying physiological mechanisms are (as far as known), will definitely help the pilot to be prepared just in case. The training value of the demonstration of The Leans is obvious: The realism of the demonstration is high, and the training relevant, since the situation is pretty much the same as in the real situation. In both simulators pilots are encouraged to get on their instruments, which guarantees in the Gyro IPT II that the illusion will not appear again, and in the Airfox that the bank sensation will disappear gradually.

3.4.5 Conclusion

In the previous section pilots had to experience various SD illusions as part of their syllabus. When they fly in these devices, they are on guard and will pay special attention to their instruments, which is the reason why the manufacturers use special effects to induce the illusions. For refresher training the ideal situation would be if the pilots could be confronted with SD during normal training tasks in the simulator, to get them by surprise, which is more close to reality. This is the subject of the next paragraph.

3.5 GROUND-BASED SD TRAINING SCENARIOS FOR FULL FLIGHT SIMULATORS

3.5.1 Introduction

Full Flight Simulators may be of use in demonstrating circumstances and facilitating training in spatial disorientation particularly for the demonstration of certain rotary-wing SD illusions. The flight simulator presents an excellent opportunity to capitalize on this training device to enhance awareness and coping strategies for helicopter operations. However, there are a few SD illusions that are not possible in a traditional flight simulator. These illusions, usually of the somatogravic or somatogyral type, require special motion platforms, preferably devices with a planetary arm (Table 3.1, category 3 or 4) or in-flight demonstrations (Chapter 4). We expect that centrifuges used for high G flight training will also be useful for SD countermeasure training in the future. Nowadays they are used to demonstrate the tumbling sensations after the stop, which is not representative for an in-flight illusion. These demonstrations mostly came to an end as soon as an SD training device from the second category became available (Table 3.1).

Spatial Disorientation training in Full Flight Simulators has been utilized by U.S. Army Aeromedical Research Laboratory (USAARL), and latterly a trial in an operational rotary-wing unit has been undertaken by QinetiQ on behalf of the RAF Centre of Aviation Medicine (CAM). Both of these will be described in turn.

3.5.2 USAARL Simulator Training

At the US Army Aeromedical Research Laboratory (USAARL), flight scenarios were developed in the UH-60 simulator [52,53]. Actual SD accident summaries from the US Army Safety Center (USASC) 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.

3.5.2.1 General Procedure and Typical Example

Once the scenario had been recorded and the simulator programmed accordingly, the outline procedure was as follows [2]:

The student flies the scenario and gets disoriented. (Note that some students may not become disoriented. Should this occur due to the student’s good judgement or pilot action, the student’s behaviour must be praised and reinforced. Either way, the student benefits from the experience.)

The IP debriefs student, explaining that this was an SD situation.

The IP then instructs “how to prevent SD.”

The IP then instructs "how to overcome SD."

An example of one of the scenario "scripts" is given below in detail.

- *The Instructor sets the Simulator Initial Conditions (type of flight – NVG in this case, location – an airfield in this case, weather conditions, visibility, etc).*
- *The student is assigned the role of pilot in command and the IP plays the role of the scenario IP.*
- *After takeoff from the airfield, the IP turns to a heading of 090 and flies at 70 knots at 100 feet AGL.*
- *The IP simulates a local area orientation flight and points out different geographical points to keep the student's focus outside the aircraft. Approximately one minute after takeoff, the IP allows the aircraft to ascend to 140 feet. After another minute or so, over terrain with limited contrast and visibility, the IP places the aircraft in an undetected 200-feet/minute descent and allows it to descend. As the aircraft descends through 30 feet, the IP asks, "Where's the ground? You have the controls!"*
- *Debriefing points: Tell the student, "That was spatial disorientation. The situation we just experienced actually occurred and resulted in an aircraft mishap. The following is a summary of the actual SD accident." (READ TO STUDENT): While in cruise flight, on an NVG local area orientation training flight late in the duty day, the IP, who was on the controls, noted that he was 140 feet above ground level (AGL). The IP began a descent to return to an altitude of 100 feet AGL as planned for the flight. The IP failed to arrest his descent and impacted a 22-foot high sand dune approximately 5 feet from the crest. The aircraft impacted the ground at 69 knots and at approximately 200 feet per minute rate of descent in a near level attitude. None of the crewmembers noticed the descent or saw the sand dune prior to impact. All crewmembers sustained injuries and the aircraft was totally destroyed.*
- *Ask the student:*
  - *"Why did this happen?" (Solicit feedback from student)*
  - *"What factors made the likelihood of SD worse in this situation?" (The following list is not exhaustive):*
    - *Lack of or poor visual cues.*
    - *Crew resource management failure.*
    - *Perception of linear motion below threshold. (Rate of descent too low to perceive)*
    - *Probable visual illusion (underestimating height above ground).*
    - *Poor awareness of the risk of SD in flight conditions.*
    - *Fatigue.*
  - *"How could this be prevented?" Suggestions are as follows:*
    - *Perform proper Crew Resource Management (CRM): The non-handling pilot (NHP) should assist the handling pilot (HP) by monitoring the radar altimeter.*
    - *Perform tasks and maneuvers in accordance with the Standard Operating Procedures applying appropriate environmental considerations.*
    - *Follow published guidance and regulations, to include crew rest/duty day restrictions.*
    - *Maintain situational awareness.*
    - *Be familiar with potential visual illusions.*

    - *"How could this be overcome?"*
        - *By performing proper aircrew coordination.*
- *Demonstrate the preventive action by performing proper aircrew coordination.*
- *Demonstrate the corrective action by increasing altitude (collective) as soon as a descent is detected by any crewmember.*
- *The student completes the internal validation questionnaire.*

3.5.3 The RAF CAM SD Simulator Training Study

3.5.3.1 Background

Recent surveys of UK military pilots and SD related UK military accidents [54,55,56,57] shown that the vast majority of significant SD incidents and SD accidents occur when the pilot is not aware that he is disorientated, i.e. they feel they are in a straight and level flight when in fact this is not the case ("unrecognised" or "Type I SD"). As such this is widely recognised by researchers and accident investigators alike as the most dangerous form of SD. Typically this occurs when the pilot loses situational awareness (SA) due to undertaking the mission objective, high workload or other forms of distraction (e.g. 'acquiring the bounce'). In addition, the most recent survey [57] showed typical difficulties in landing with limited or unusual references. An example incident from Joint Helicopter Command (JHC) pilots from the current survey (still undergoing analysis) is provided here:

"At night - no NVG. Over the sea – some cloud cover – nil rain. Flying at 200 ft to 400 ft. Radar Altimeter was set at 100 ft. We were given spurious positioning and directions back to the ship. While trying to pinpoint position with onboard navigational equipment, the aircraft started to descend unknown to the crew. We were alerted by the radar altimeter and recovered as the altimeter was reading 40 – 50 ft. As handling pilot, I was distracted and neither of us realised we were descending fairly rapidly, due to lack of light and lack of visible horizon."

One solution to prevent these types of SD incidents and accidents is to provide SD training, where aircrew can fly themselves into a situation engineered to produce unrecognised SD. This can be safely and readily achieved in a flight simulator, using scenarios designed to produce a loss of SA. Flight simulators provide a high-fidelity environment in which to practice new skills, and have the performance measurement facilities that are essential for any structured training and feedback programme.

To this end, a programme of research has been undertaken for the Royal Air Force Centre of Aviation Medicine (RAF CAM) to investigate the feasibility and effectiveness of conducting SD training in flight simulators. This has utilized the Griffin simulator based at RAF Shawbury. The trials were conducted using students from the Multi Engine Advanced Rotary Wing Courses conducted by the Defence Helicopter Training School during 2005 – 2007.

3.5.3.2 Trial Overview

The trial, which ran during the period January 2006 – January 2007 consisted of two independent groups of subjects; those who were trained in recognising, avoiding and recovering from SD in the simulator (the SD Trained Group) and those who did not receive such training (the Control Group). The SD Trained Group undertook four 1.5 hour SD training sessions (comprising 2 scenarios per session), placed approximately 2 – 4 weeks apart in the flight simulator training programme. This was followed, approximately 3 weeks post their final SD training session, by a 'test' scenario in the simulator, designed to evaluate their skills in anticipating, recognising and dealing with SD in-flight. The Control Group completed the test scenario at the same point in their simulator training as the SD Trained Group (see Figure 3.5). The performance of the SD Trained and Control Groups in the test scenario was compared to assess the effectiveness of the SD training.

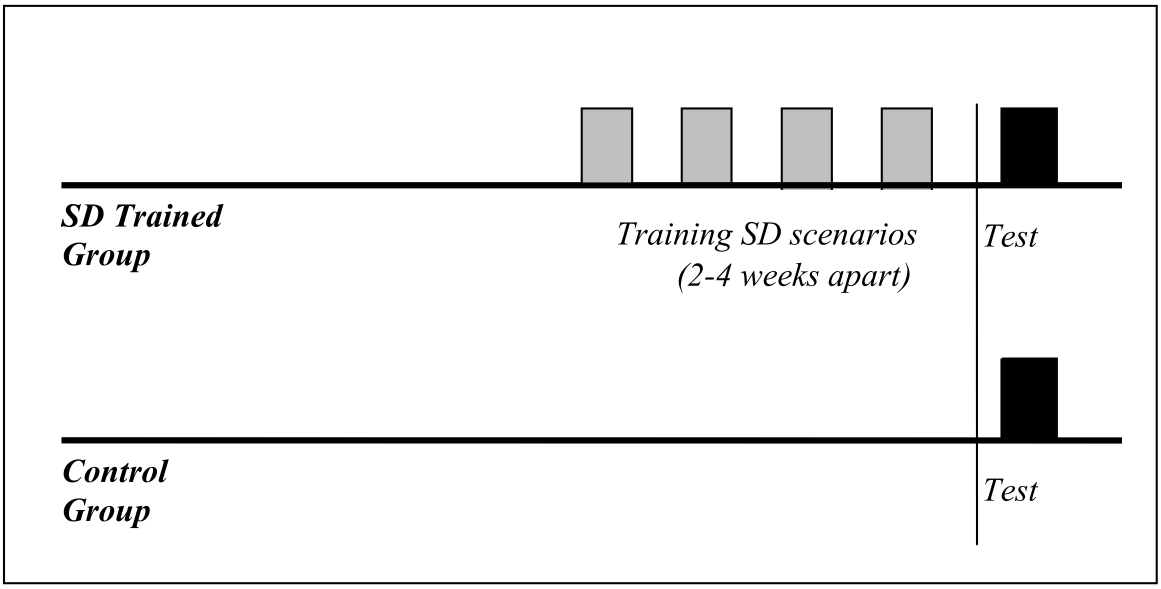

Figure 3.5: Diagrammatic Representation of the Trial Design.

The SD Trained Group comprised pairs of pilots (alternating as HP and NHP), with the students changing seats and thus roles after the first of each pair of scenarios. The pilots undertook two similar SD scenarios within each 1.5 hour training session, one as the nominated aircraft commander flying in the Right Hand Seat as the HP and the other in the Left Hand Seat as the NHP. The scenarios were flown in a sequence of pairs, each pair covering similar objectives, with the students changing seats and thus roles after the first of each pair of scenarios. The scenarios were designed to have a definite start and completion in order to maintain the realism as far as possible. The rationale behind this design was that the two similar scenarios should reinforce the problems that can be encountered and how they should be addressed. The students were debriefed together and then assessed by the instructor individually at the end of each session. Both the SD trained group and the Control group flew the final assessment scenario as the HP.

The philosophy of the approach to SD simulator training outlined here and the entirety of this research programme is one of educating pilots to the consequences of not maintaining SA (i.e. the risk of SD). As such, the scenarios have been designed to help pilots develop skills for the maintenance of SA. If a pilot develops these skills in the safety of the flight simulator it is thought that, along with other skills, these will readily transfer to the real flight environment, and as such prevent the occurrence of incidents (and therefore potentially accidents). Key to this philosophy of this trial was that the students were unaware (as far as possible) that they were undertaking a trial into SD. This was essential in order to prevent any pre-conceived ideas on how they felt they should perform.

3.5.3.3 Scenarios

The scenarios were designed to generate common situations where SA can be readily lost therefore increasing the risk of SD (e.g. inadvertent IMC, flight over featureless terrain, etc.). They were also designed to demonstrate that adherence to procedures would prevent an already difficult situation developing into one which was unrecoverable. Additionally, the scenarios provided a graphic demonstration of the importance of good CRM which allowed the HP to continue to fly the aircraft whilst the NHP dealt with the secondary issues.

3.5.3.3.1 Scenarios 1 and 2: Inadvertent Entry into Instrument Meteorological Conditions (IMC) with Incorrect Instructions from Air Traffic Control (ATC).

SD Training Scenario – 1 (Captaincy, Incorrect ATC instructions)

The crew are tasked to fly visual circuits at Shawbury, with auto pilot out. Visibility is 4000 m in rain, cloud base 1200 ft. As the aircraft turns downwind the cloud base reduces to 300 ft to cause inadvertent IMC. By setting such a low cloud base this will reinforce the basic teaching of not trying to regain VMC but to continue on instruments. The wind is 200/20. Once IMC the crew are informed that the PAR is unserviceable but the ILS is working. When given the heading to establish the localiser, ATC gives a heading of 120º instead of 210º.

SD Training Scenario – 2 (Captaincy, Secondary problem)

Tasked to conduct an in-flight power check at 3000 ft above ground level at Maximum Continuous Power (MCP) in the West and then to recover in normal manner through Harmer Hill. Weather conditions are an inversion at 2000 ft with visibility below the inversion <1000 m. Time of day to be 0800 with a low, bright sun. The conditions should be manipulated such that as the aircraft is carrying out the power check the visibility at high level, down sun, is >10 km but as the aircraft descends and turns back towards Shawbury the visibility becomes progressively worse until <1000 m at 1000 ft looking into sun. Runway in use 23, wind slack. The instructor should ensure that the aircraft is positioned well west of Harmer Hill before allowing the student to descend to compound the navigational difficulty. As the aircraft is descending, the compass should be failed.

Learning objectives covered by Scenarios 1 and 2:

- To assess impact of weather on conduct/continuation of task;
- To make use of navigation equipment to determine position and interpret ATC mistake;
- To act as a crew and assist one another, especially the NHP;
- To be ready for subsequent other problems, instrument failures etc.;
- To make full use of available agencies to assist; and
- Observance of weather limitations.

3.5.3.3.2 Scenarios 3 and 4, Situational Interpretation

SD Training Scenario – 3 (Situational Interpretation)

Night field landing site to T. Crew fly from Shawbury to the T (Chetwynd). They are given the T orientation (180º) and the weather – light winds, generally from the south at <5 kts and the possibility of mist forming during the period. The wind is actually set as 000/10 with a low, light mist at the Landing Site (LS).

SD Training Scenario – 4 (Secondary problem)

The crew is tasked to fly to and land at a night landing T positioned on the Long Mynd glider site. The weather is CAVOK (Cloud and Visibility OK) at night with no moon. The T is orientated such that it is sitting on an upslope on final approach.

Learning objectives covered by Scenarios 3 and 4:

- To assess a situation for differences to the expected plan.
- To amend plan to fit the circumstances.
- To make use of aircraft instruments to identify problem.

- To work as a crew to monitor HPs actions and situational assessment.
- What is seen is not what it appears.
- Perceptions can be confusing – trust the instruments.
- Landing sites away from airfields may not be situated on level ground.
- All crew members to play a full part in the safe conduct of a flight.

3.5.3.3.3 Scenarios 5 and 6, Weather Minima

SD Training Scenario – 5 (Weather Minima, Instrument failure, ATC error)

Tasked to carry out a low level navigational exercise (200 ft, daylight) from Welshpool airfield down the valley to Bishops Castle and then to Church Stretton (The student should be given a marked map and allowed a short period to plan, in order to make the sortie realistic). Briefed that the weather is poor but within limits and is potentially deteriorating. The weather should deteriorate as the aircraft flies down valley until at some point (crossing A489 by Church Stoke) the aircraft goes inadvertent IMC. If the pilot makes the correct decision to abort the sortie and return to Shawbury, the weather should be reduced to below limits as he turns to force the aircraft into IMC. As the aircraft pulls up to climb to above safety altitude, the main Attitude Indicator (AI) fails (Pilot's Vertical Gyro Fail).

SD Training Scenario – 6 (NVG, Weather Minima, Loss of RT)

The crew have taken the aircraft on a Rotors Running Crew Change with sufficient fuel for the sortie (1 hour duration – 1000 lbs) of a Night Vision Goggle training sortie. The route is out of Nesscliffe Camp to Pontesbury and then through the hills to field 21. Weather forecast is an approaching front by end of period but conditions currently above minima. Approaching Pontesbury enter low cloud/fog. On pull up into cloud, initial contact with ATC but then loss of radio transmission (RT). Due to the low fuel state, there is no option but to recover to Shawbury to carry out ILS.

Learning objectives covered by Scenarios 5 and 6:

- To be aware of implications of deteriorating weather;
- To cross check instruments;
- To be aware of the local topography and the restrictions it places on an abort;
- To check that ATC instructions can be complied with in safety;
- Correct actions following loss of RT when IMC; and
- Ability to self position for ILS.

3.5.3.3.4 Scenarios 7 and 8, Featureless Terrain, System Failures

SD Training Scenario – 7 (Night, poor ground definition, system failure)

The crew are tasked to fly from Valley, run way 32 to an oil rig, 10 nm offshore, to take a doctor to a casualty with a life threatening injury. It is a winter night, visibility 10 km in rain, cloud OVC at 1500 ft, wind 350/15G25, moderate turbulence, temperature +5 ºC. En-route the weather deteriorates to 5000m 1000 ft AGL, remaining within legal night weather minima. If the pilot considers/elects to abort due to conditions, pressure should be applied by the rig to complete the task due to condition of casualty. If an abort is carried out the weather should deteriorate below minima forcing an IMC recovery, in icing conditions. The only aid available for an Instrument Flight recovery is the ILS on Runway 14. The wind should remain northerly to force the approach to be from the S/SE which places the rig on the left of the aircraft on finals, compounding the difficulties of orientation and making the approach more difficult in an already high workload situation.

SD Training Scenario – 8 (Dusk into night, poor terrain, urgent situation)

The crew are tasked to fly from Valley to RFA Argus to collect a Very Seriously Ill (VSI) casualty. Ships position given as a Lat/Long and also as a brg/dist from the RAF Valley TACAN, VYL 240/20. The weather is 8000 m, OVC 1500 ft, +10, 280/20. There is an approaching cold front currently lying to the north of the ships position (this weather situation can be given to the crew as a synoptic). Post frontal conditions are 350/15G25, OVC 1000 ft, showers, +5. A contact frequency for Argus is given prior to departure. No RT contact until at 5 nm when a change of location is given as a Lat/Long. (N 53 17.8 W 004 45.0, this position is 290/10 from the VYL). The new location places the ship N of the front. The crew are informed of the deterioration of the casualty in order to pressurise them into completing the task. As the aircraft passes through the front en-route to the ship, night should fall and the weather deteriorate to marginal conditions. If they elect to abort the mission and return to Valley, they should go inadvertent IMC and be confronted with an icing accretion problem.

Learning objectives covered by Scenarios 7 and 8:

- Be aware of difficulties of flight over unlit, bland terrain;
- Be aware of potential problems of flight in marginal conditions;
- To make full use of available systems to reduce workload;
- To allocate tasks within crew to deal with equipment failures;
- To be aware of the consequences of deliberately flying in uncleared conditions, i.e. icing conditions;
- To not allow pressure to continue with a task to take precedence over safe flight; and
- Be prepared to make full use of external agencies to either complete the task or recover the situation.

3.5.3.4 Results

Statistical analysis of the Instructor Rating Criteria data showed that the SD Trained Group coped significantly better in terms of maintaining situational awareness and crew resource management than the Control group (see Figure 3.6). They were also rated by the instructor as more prepared for the unexpected (i.e. had a plan to implement in various situations such as inadvertent IMC or other emergency)?" In addition, in the Control group there was greater percentage of 'almost CFIT' (Controlled Flight Into Terrain) or 'crashes' than the SD Trained Group (see Figure 3.7). An example of the rating criteria (here for the Question "Did the student rectify the problem?") is provided below:

1) Not at all, flight safety was at risk;
2) Detected one or more but outside of an acceptable timescale, flight safety could have been at risk;
3) Rectified one or more within an acceptable time period but could have been much better, large scope for improvement;
4) Rectified all problems within an acceptable timescale, some room for improvement; and
5) Rectified all problems very rapidly and efficiently as the scenario developed, little room for improvement.

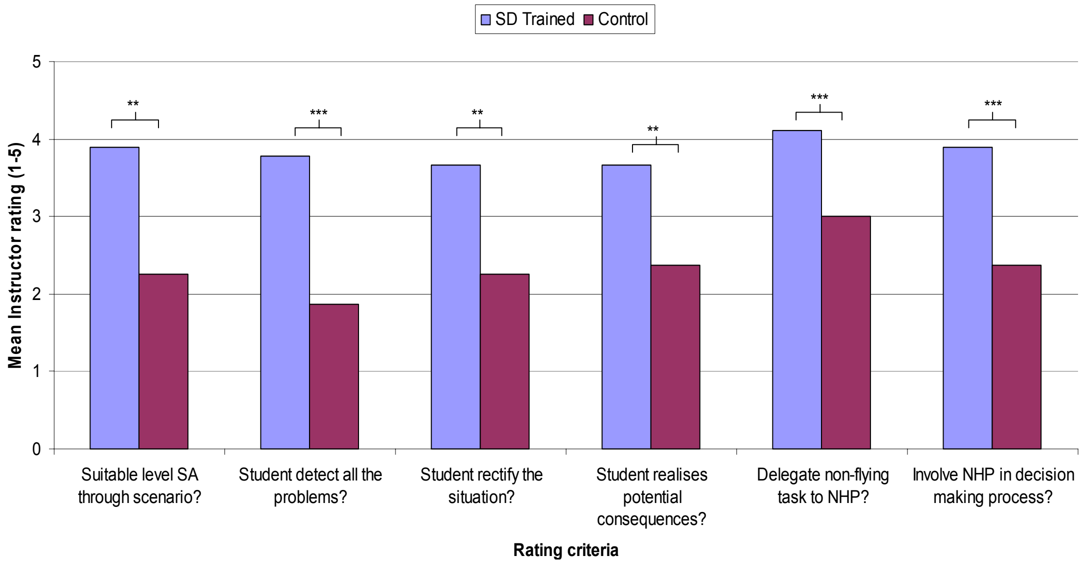

Figure 3.6: Mean Instructor Ratings for the SD Trained and Control Groups in the Test Scenario (p < 0.01, *** p < 0.001).**

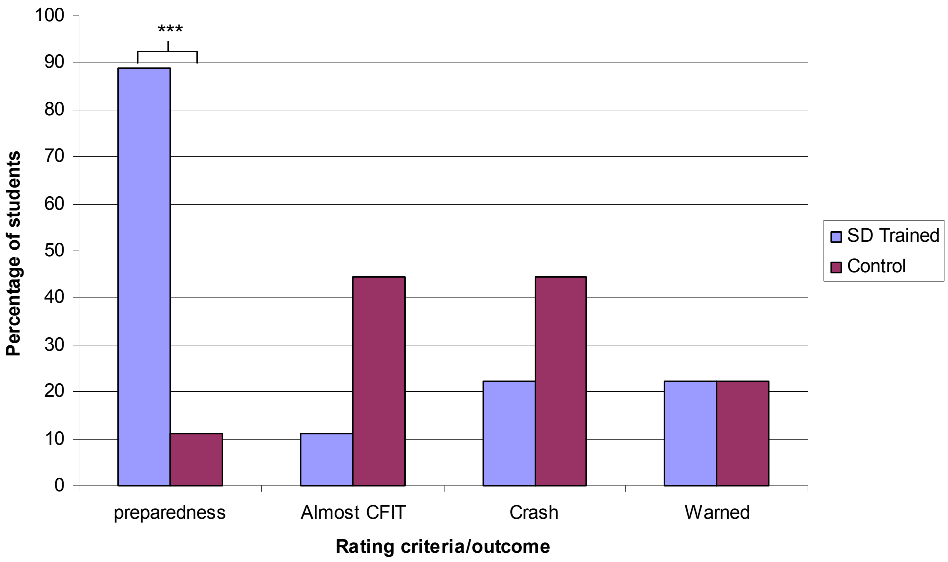

Figure 3.7: The Percentage of Students in the SD Trained (n = 9) and Control Groups (n = 9) in the Test Scenario who were Rated by the Instructor as Well-Prepared for the Unexpected; also the Percentage of Students where the Outcome of the Scenario was almost CFIT, a Crash, or Warning from External Stimuli/RADALT (*** p < 0.001).

The SD simulator training was very well-received by the students. Feedback in terms of lessons they believed they had learned included:

- "Always try and fly the aircraft first and think of all possibilities during diagnostics."
- "Multiple failures can occur. When it gets busy and you are unsure of what has/is happening you need very good CRM."
- "To cross check instruments especially when already experiencing difficulties."
- "Don't push into bad weather with NVGs."

- "Priority, delegate. If you use this then it increases your capacity and allows you to logically work through the problem."
- "Always be prepared for such situations especially on days where the met is already poor."

3.5.3.5 Conclusions

In summary, this study has shown that using scenario-based SD training is beneficial in terms of improving student skills pertinent to maintaining situational awareness and good CRM. Allowing the students to be in total control of the prosecution of the tasks with no instructor involvement increased their confidence in their ability to deal with unexpected situations. It also allowed them to put into practice techniques which may have been discussed but which they had not had the opportunity to carry out in flight. In short, the training is a very cost effective way of teaching pilots the importance of SA and CRM in avoiding spatial disorientation, especially the most dangerous, insidious SD, and a low-cost alternative to the technological solutions that have been debated in recent years.

3.5.4 Usefulness of Full Flight Simulators for SD Training

USAARL concluded that these scenarios provided valuable training material that will have a positive impact on reducing SD mishaps [58]. USAARL's liaison with the US Army Safety Center has ensured that the scenarios reflected the actual accident as much as possible and that the scientific background to the scenarios and the associated debrief were sound. Eighteen scenarios have been validated in the UH-60 simulator and the majority adapted for the AH-64 Combat Mission Simulator [59]. USAARL continues to monitor the training package to assess the impact on attitudes and practice after distribution [53]. It is vital that the scenarios are not viewed in isolation, but as the central part of a complete training package that is part of the larger training process. The intention is that the scenarios will be reviewed periodically in consultation with the USASC and other agencies. USAARL will continue to produce new scenarios and scripts in response to the Army's accident trends, ongoing research, and evaluation of the training package's practical use in the field.

The approach in the RAF CAM study differed from the approach in the USAARL SD simulator training programme. Whereas the USAARL students were aware they were receiving special SD training, the RAF CAM study group was, as far as they were aware, just undertaking a flight in the simulator. This was to highlight how readily loss of SA and risk of SD can occur within the context of a regular flight, and to prevent any preconceived ideas of SD affecting their behavior. Both approaches have merit and are complimentary. At present QinetiQ are investigating the feasibility of SD simulator refresher training on behalf of the RAF CAM. It was hoped that refresher training will aid retention of the key skills required to avoid spatial disorientation, as established by the RAF Shawbury trial.

Organizations that are responsible for SD training, and do not have access to a SD demonstrator/trainer, are encouraged to evaluate the usefulness of flight training simulators to demonstrate SD situations. If further training by this method were employed, an economy of resources would soon be realized. Scenarios should be weapon system specific, including components of previous accidents, high-risk phases of flight, or system anomalies. They should also be multitask, high workload with a console operator capable of instructing in the maintenance of ongoing orientation. Examples of potential scenarios are:

- Low level abort into weather;
- Maneuvering over water with a hazy horizon;
- Tanker rendezvous/rejoin at night with reduced visibility; and
- Cockpit distraction or novel situation such as CRT and mission data computer failure while on NVGs.

The primary purpose is to place aircrew in a situation where there is a high risk to becoming disoriented, and then train them to always know where they are in space, while simultaneously operating the weapon system. In essence, the concept is to rehearse high-risk profiles to amplify the mental model and free up short-term memory during real flight. Such a syllabus should be required at the following points:

- Advanced flying training;
- Operational flying training units;
- Upgrade to flight lead or instructor pilot;
- Conversion to a new aircraft;
- Standardization/evaluation check rides; and
- Annually.

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. As stated in the introduction to this section, not all illusions are easily induced in a standard hexapod platform, which means that an analysis on the motion profiles is definitely required (see Section 3.4.3.6, Motion Cueing Requirements).

Chapter 4 – IN-FLIGHT SD TRAINING

4.1 ROTARY WING IN-FLIGHT DEMONSTRATION OF SD ILLUSIONS

4.1.1 Introduction

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 [25].

There is good evidence from the British Army Air Corps' experience that the sortie is best initially flown just before students learn instrument flying in helicopters. In order to aid understanding and awareness, the period since students have attended aeromedical lectures on SD should not be too long. Although this evidence holds for student-pilots for helicopters, it is reasonable to assume that the same holds true for FW student-pilots.

The illusions to be described occur in real flight particularly in total darkness or in conditions of poor visibility. This is realized by the subject student-pilot having his eyes closed during the demonstration. In the forward flight maneuvers he is instructed to close his eyes when the helicopter has reached the described forward air speed at the requested altitude. This holds for all the demonstrations described in this section, and will therefore not be repeated in the description of each separate illusion.

4.1.2 Examples of Rotary-Wing SD Demonstration Maneuvers

During the RW-demonstrations the student-pilots are always passengers. One is subject of a particular demonstration, who reports about his orientation, while the others are observers. Their role changes such that everybody has played both roles sufficiently.

There are basically five maneuvers, four of which start with a forward flight, and one that starts from hover. A short description of these maneuvers and the essential debriefing is giving below.

4.1.2.1 Level Turn

From straight and level flight a coordinated turn is executed while maintaining airspeed and altitude. The response of the subject allows for discussion of the limitations of the semicircular canals in the debriefing.

4.1.2.2 Straight and Level

A straight and level flight is maintained for some time at 90 – 100 knots. Students report variable motion due to the turbulence and the aerodynamic response of the helicopter, which allows the debriefing about the effects of brief stimulation of the kinesthetic receptors and vestibular apparatus.

4.1.2.3 Straight and Level Deceleration

A deceleration from the initial 90 – 100 knots to less than 30 knots within 30 – 40 seconds during straight and level flight, without change of heading or altitude. Subject often reports a climb, allowing in the debriefing to discuss the absence of accurate physiological perception of airspeed.

4.1.2.4 Inadvertent Descent

The student closes his eyes while flying straight and level at 90 – 100 knots about 500 ft above ground level (AGL). While initiating a descent at below 500 feet per minute, a series of turns is commenced. The subject reports his heading, height, and airspeed, when the aircraft is established in flight below 50 feet AGL, and then opens his eyes. The descent is usually not perceived, which makes the point clear in the debriefing of the danger of inadvertent descent.

4.1.2.5 Hover

Demonstrations start from a 5- or 6-foot hover. Students are exposed to a variety of linear and rotational movements while maintaining hover height. Subject has to give a running commentary, which helps to exacerbate the onset of SD. Within these exercises various maneuvers are "hidden" so that when the student opens his eyes, a dramatic end point is evident: this may be either climbing backwards at 10 – 15 knots, landing without the subject realizing it, or a gentle transition to forward flight. Most aircrew are able to maintain their orientation for only 10 to 15 seconds. These exercises have a most educational effect upon the subject and observing students. In the debriefing the poor ability to detect linear movements is discussed, and the relevance of physiological orientation limitations in the context of snow, sand, and night operations is emphasized.

4.1.3 Organization

The Demonstration Procedures for the demonstrations just described would be ideal if three students are flown on each sortie. Each experiences one of the forward flight maneuvers and one of the hover maneuvers. Flying the sortie with three students is also the most cost-effective solution. The sortie should not be flown with less than 2 students, as there are distinct benefits from observing the reaction of peers as well as experiencing the maneuvers themselves.

During the transit to the demonstration area, the Flight Surgeon (FS) briefly revises the physiology of the orientation senses. A series of forward flight and hover maneuvers is then conducted. In turn, personnel are asked to sit free of the airframe structures other than the seat, note the aircraft's initial flight parameters, close their eyes and lower their dark visor, and as the "subject" for that maneuver, to give a running commentary on their perception of the aircraft's flight path. In this way, the "subject" is deprived of vision, the most important orientation sense, so that the limitations, particularly the unreliability of the non-visual orientation senses, could be demonstrated. The other two personnel (observers) are asked to observe but not comment until after the maneuver is complete. The FS then debriefs the individual maneuver. All students experience at least one maneuver in each of the forward flight and hover groups.

4.2 FIXED WING IN-FLIGHT DEMONSTRATION OF SD ILLUSIONS

4.2.1 Fixed Wing SD Demonstrations

The RAF designed a SD demonstration in Fixed Wing (FW) aircraft for high performance flight profiles in the Hawk [2]. 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.

Nevertheless, the demonstrations are convincing since the stimuli are the real flight profiles. The effect of the demonstration is enhanced by giving the student control of the aircraft (still with the eyes closed), mostly with the instruction to fly straight and level. When he/she opens the eyes, the effect of the demonstration is pretty optimal. This procedure requires that the subject has at least some basic know-how about aircraft handling (10 – 15 lessons).

Eight SD maneuvers have been identified for the FW SD demonstration. All demonstrations start from flying straight and level at a certain height and speed. At that moment the subject is requested to close his eyes and the demonstration maneuvers start. The maneuvers are described in Section 4.2.2.

4.2.2 Examples of Fixed-Wing SD Demonstration Maneuvers According to AIR STD 61/117/13

The following examples have been developed for demonstration in high-performance aircraft [32,2]. In transport aircraft demos 4.2.2.2, 4.2.2.3, 4.2.2.4 and 4.2.2.5 were found to be very useful too; the other demos need slight modifications to induce the described illusions.

4.2.2.1 Pitch Misperception During Acceleration

The student is instructed to close his/her eyes. The IP accelerates the aircraft from 150 knots. The student is then asked to estimate the perceived pitch change. Alternatively he/she is given control of the aircraft (with eyes still closed) and instructed to maintain level flight. The result is either a perceived pitch up sensation or the student pushes the nose over if he has been given control.

Debriefing points: This illusion results from the linear acceleration acting on the otoliths of the inner ear. The resultant vector from the linear acceleration and normal gravity gives the sensation of an increase in pitch. Such a somatogravic illusion can occur in a phase of flight of sustained acceleration, such as on takeoff, particularly in afterburner or catapult launches. In order to overcome the sensation of an increasing pitch attitude, the pilot will pitch the nose down and, if not attentive to the actual aircraft attitude, will result in controlled flight into the terrain (CFIT).

4.2.2.2 Elevator Illusion

The student is instructed to close his eyes. The IP establishes a constant rate climb/descent and then levels off. The student is given control of the aircraft (with his eyes still closed) and instructed to maintain level flight. The result is that the student re-enters a climb or descent.

Debriefing points: This illusion can occur during a constant rate climb on a standard instrument departure (SID) with an intermediate level off, or during descent on an instrument approach with an intermediate level off. The pilot misperceives the resultant G vector associated with the pitch angle and, if not attending to the attitude indicator upon level off, will tend to resume the climb or descent to achieve the same "seat-of-the-pants" feeling. At best the pilot will be violated for busting a hard altitude; at worst, a stall or CFIT will happen.

4.2.2.3 False Climb in a Turn

The student is instructed to close his eyes. The IP slowly (< 2 deg. sec2) achieves 45° AOB. The student is asked what attitude he/she perceives and is given control of the aircraft (with eyes still closed) and instructed to maintain level flight. The result is that the student perceives a climb, lowers the nose and descends.

Debriefing points: This is another somatogravic illusion that can subtly occur anytime during flight, in VMC or IMC, if the pilot is not attending to the actual aircraft attitude. If one unknowingly allows a sub threshold turn to occur, especially in level flight, the pilot will sense the increased G and, thinking that the aircraft is still wings level, will sense that the aircraft is climbing. The natural corrective control input would be to lower the nose. If operating at low altitude, the result would be disastrous.

4.2.2.4 Diving During Turn Recovery

The student is instructed to close his eyes. The IP sustains a 1.5 G turn and then recovers to straight and level flight. The student is asked for his/her perception of the aircraft's attitude during recovery. The result is that the student perceives a nose down pitch change with recovery to the 1G environment.

Debriefing points: This somatogravic illusion is opposite to the preceding one. In this case, the pilot is in a known sustained turn with the associated increase G level. If not attending to attitude and performance instruments, the pilot will sense the lesser 1G environment upon rollout and feel like the aircraft is descending. The tendency will be to raise the nose of the aircraft. This often occurs, for instance, when a student practicing steep turns climbs during turn reversal because of the decreased G passing through level flight.

4.2.2.5 The Somatogyral Illusion

The student is instructed to close his eyes. The IP conducts a 270 – 360° of turn at 30° AOB and then recovers to straight and level flight (at a supra-threshold rate). The student is asked to describe the aircraft's attitude. The result is that the student perceives a turn in opposite direction.

Debriefing points: Every instrument rated pilot has experienced this somatogyral illusion. During IMC flight, a suprathreshold roll in the opposite direction from an established turn (that feels like level flight) sets up the appropriate rotatory stimulus in the semicircular canals. Now the pilot feels the aircraft is in a turn in the opposite direction, even though the attitude indicator shows straight and level flight; hence, the leans.

4.2.2.6 Post Roll Effect

The student is instructed to close his eyes. The IP establishes 45° AOB, and then rolls 90° in the opposite direction. The student is given control of the aircraft (with his eyes still closed) and instructed to maintain the aircraft attitude. The result is that the student increases the roll and allows the nose to drop.

Debriefing points: This illusion, possibly prominent in several low-level CFIT accidents, is primarily somatogyral in origin, although there could be a somatogravic component. During roll reversal, the pilot can sense a roll in the opposite direction and compensate by increasing the roll in the direction of turn. If not attending to the real aircraft attitude while attempting to maintain the same "seat-of-the-pants" sensation, the pilot simultaneously allows the nose of the aircraft to drop. The increasing roll rate and decreasing pitch attitude will result in an unusual attitude at cruising altitudes, and impact with terrain at low-level.

4.2.2.7 Tilt with Skid

The student is instructed to close his eyes. The IP puts in full rudder trim and then the student is asked to describe the aircraft's attitude. The result is that the student perceives a sensation of tilt.

Debriefing points: When cross-controlling an aircraft (admittedly rare in modern fast jets) a pilot could get a somatogyral input about the yaw axis that is interpreted as a tilt or perhaps a roll. The reaction would be to input controls to counter the perceived aircraft motion. This may happen when applying rudder to counter a crosswind condition. If in IMC, the pilot could enter an unusual attitude.

4.2.2.8 Coriolis Cross-Coupling Effect

With the student's eyes open, the IP performs at least four continuous aileron rolls. The student is then instructed to move his head out of the rotating plane (forwards or to one side). The result is that the student perceives a tumbling sensation.

Debriefing points: From the time that we entered pilot training, we have all been cautioned about moving our heads in the cockpit because of the Coriolis Effect. Although a rare occurrence during flight, continuous aileron rolls effectively induce somatogyral motion about the longitudinal axis. Once the pilot places his head out of plane, a tumbling sensation ensues, but is short-lived.

4.2.3 Organization

The originators of the demonstrations stress the point that no extra training sortie is required to perform this FW SD demonstration. The eight illusions can be flown in a total time of about 20 minutes. Alternatively, a few can be demonstrated on several sorties, either en route to a training area or returning to base. However, it is imperative that the training objectives be established.

For internal feedback and validation, a debrief form to be completed by students after the demonstration is very useful, both for RW and FW SD demonstrations. For larger air forces the ultimate value of this method of increasing the SD awareness of aircrew can be assessed by external validation in the reduction of the SD accident rate.

Whenever possible, a demonstration to further reinforce education in the limitations of the orientation senses in flight should be performed in a basic aircraft of the type to be flown by aircrew. This should be part of the initial training and repeated at regular intervals. It is desirable that this sortie is flown by a medical officer pilot (flight surgeon) in order to explain the mechanics of SD. In air forces without medical officer pilots, this task may be accomplished by specially trained flying instructors. Such demonstrations are best achieved with other students observing the subject.

4.3 IN-FLIGHT SD TRAINING SCENARIOS

In-flight SD training implies learning flying procedures that anticipate disorientating circumstances and coping with the illusions once they have been encountered. This is the remit of the flying instructor and should take place in both simulator and actual flying sorties in both initial military flying training and as part of regular continuation and aircraft conversion training. Spatial orientation is a component of the aviator's more comprehensive perception and appreciation of the tactical flight environment, which is referred to as situational awareness. Consequently, a pilot who has an erroneous perception of aircraft orientation also suffers from a loss of situation awareness, but loss of SA can occur for many different reasons in the absence of any spatial disorientation. Obviously SA encompasses factors beyond the scope of this SD report and will not be treated in detail.

4.3.1 Management of SD in Flight

With present technology, training in the management of recognized (Type 2) SD is limited to recovery from unusual attitudes and action upon inadvertent entry to Instrument Meteorological Conditions (IMC) [2]. These topics must be established as training objectives and not merely demonstrations. Training will be aircraft type specific and, although some generic training may be possible on initial flying courses, further training will be required when a pilot first encounters different climatic or operational scenarios (e.g. helicopter snow landings). Therefore inclusion of these objectives in all pilot training courses is the minimum requirement, but further specification is not possible.

4.3.2 In-Flight Training

Learning and thence demonstrating competence in handling in-flight disorientating circumstances and illusions, e.g. recovery from unusual attitudes and procedures for inadvertent entry to IMC. This is the responsibility of flight instructors (who have themselves been appropriately trained to teach the procedures and assess competence).

Most modern air forces already incorporate some training of this sort described above. Standardization of the training objectives will be of great benefit in providing a common training base for aircrew on joint and combined operations, the goal being a commonality in experience and expertise. This is one of the goals of both NATO and the Air Standards Coordinating Committee (English-speaking nations).

SD Training should be conducted during both elementary and advanced (including operational conversion) flight training, and also during conversion to each specific aircraft type. An assessment of skills should also be made during revalidation of an instrument flying rating.

The following are considered the **minimum** requirements for which a training objective is to be stated [2].

4.3.3 Inadvertent Entry into IMC

Procedure: During a training flight in VMC, the instructor will announce a simulated inadvertent entry to IMC. If the aircraft is appropriately rated, the procedure is to be performed during both day and night flight. It will also be performed during flight with NVDs if the aircraft is appropriately equipped and the student rated on NVD.

Objective: The student will correctly perform the procedures for inadvertent entry to IMC, i.e. immediate reversion to flight by reference to the primary flight instruments. Indicated airspeed and vertical speed are to be appropriate to the aircraft type. A climb to the safety altitude is to be achieved.

4.3.4 Recovery from Unusual Attitudes

Procedure: During a training flight in simulated IMC (e.g. blackout screens/visors fitted to the aircraft/student) and with the instructor acting as safety pilot, the student is to be instructed to close his eyes while still on the controls. The safety pilot may release the automatic flight control system (AFCS) and stability/trim control to assist departure from the stable flight parameters. When the aircraft has significantly departed from stable flight (a significant departure may be a change of heading of at least 30 degrees, but depends of course on aircraft type), the student is to be instructed to open his eyes and return to the original flight parameters (altitude, heading and airspeed).

If this procedure fails to induce an unusual attitude (UA), or significant departure from the original flight parameters, the instructor is to fly the aircraft into a UA while the student sits free of the controls with his eyes closed. The instructor will then hand control back to the student who is to recover the aircraft to the original flight parameters.

Objective: Both the techniques to regain both proper control of the aircraft and a return to the original flight parameters are to be performed correctly. Although the precise procedures are aircraft dependent, the general principles are as follows:

- Wings level;
- Pitch level;
- Apply appropriate power setting; and
- Return to original airspeed, altitude and heading.

The unusual attitudes to be achieved may be specified in the Instrument Rating Test documents. An example for helicopters is:

- An autorotative turn at low indicated airspeed and not more than 30° angle of bank.
- A descending turn at high indicated airspeed and not more than 30° angle of bank.

4.3.5 Training the Trainers

Flight Instructors are to be taught to perform and assess these procedures during their own instructor training (see also Chapter 7).

Chapter 5 – SD AVOIDANCE TRAINING FOR NIGHT VISION DEVICES

5.1 GROUND-BASED DEMONSTRATION OF SD ASPECTS OF NIGHT VISION DEVICES

5.1.1 Introduction

Night vision devices, such as night vision goggles and thermal imagers, have their limitations that result in an impairment of visual perception. The perception is not only degraded, it regularly also leads to *visual illusions*, the misjudgement of visual features, which may cause SD. The experience of a visual illusion can make a big impression, even an emotional impression. When the world is not as our eyes tell us, our confidence decreases. Hands-on demonstration of these effects greatly enhances the NVG training program. There is a clear need for an entry-level NVG training program to familiarize inexperienced personnel with these fundamental and surprising NVG issues. Such training shows the visual limitations experienced with NVGs, and provides methods to identify and deal with these limitations, preventing SD. On the surface, NVG imagery appears to have a structure similar to daylight imagery. However, in actuality its characteristics differ significantly from those of daylight imagery, inducing frequently visual illusions. In general, existing NVG courses mainly adopt a classroom approach, with relatively little hands-on experience. The majority of the training takes place in the air during NVG flights. Moreover, the main focus of the courses is on NVGs with little attention for the combination with thermal imagers.

The essential SD provocative visual limitations of real NVG imagery can be demonstrated in the ground-based SD demonstration program.

5.1.2 Image Degradation

The basic psychophysical parameters that determine the quality of NVGs are visual acuity, field-of-view, and contrast sensitivity. Using simple psychophysical tests these parameters can easily be measured by observers. By also measuring the same parameters in daytime, the quality of an NVG can be compared to standard daytime vision as is shown in Figure 5.1 [60].

Not only is intensified imagery of lower quality, it is also different due to the following four effects:

> *Reflectivity by Chlorophyll*. Chlorophyll is a green pigment found in most plants and is responsible for light absorption to provide energy for photosynthesis. It reflects most of the near-infrared light where NVGs have their peak sensitivity, just outside the visible part. As a result chlorophyll looks very bright in NVGs which gives scenes an unnatural appearance.
>
> *Shadows.* The degradation of image quality is not uniform all over the scene, but depends on local scene illumination. Details that are normally well lit remain visible at low light levels, whereas details that are in the shadows are much more reduced in visibility when the light levels drop.
>
> *Color.* NVGs do not provide color, just greenish images. As a result untrained observers are inclined to interpret terrain as being vegetated.
>
> *Halos.* NVG images usually represent luminous objects with bright circles around them, called halos. The size of these halos is independent of the distance to the bright object, and can therefore not be used as a distance cue. Moreover, halos wash out all details in the direct surrounding of the bright object.

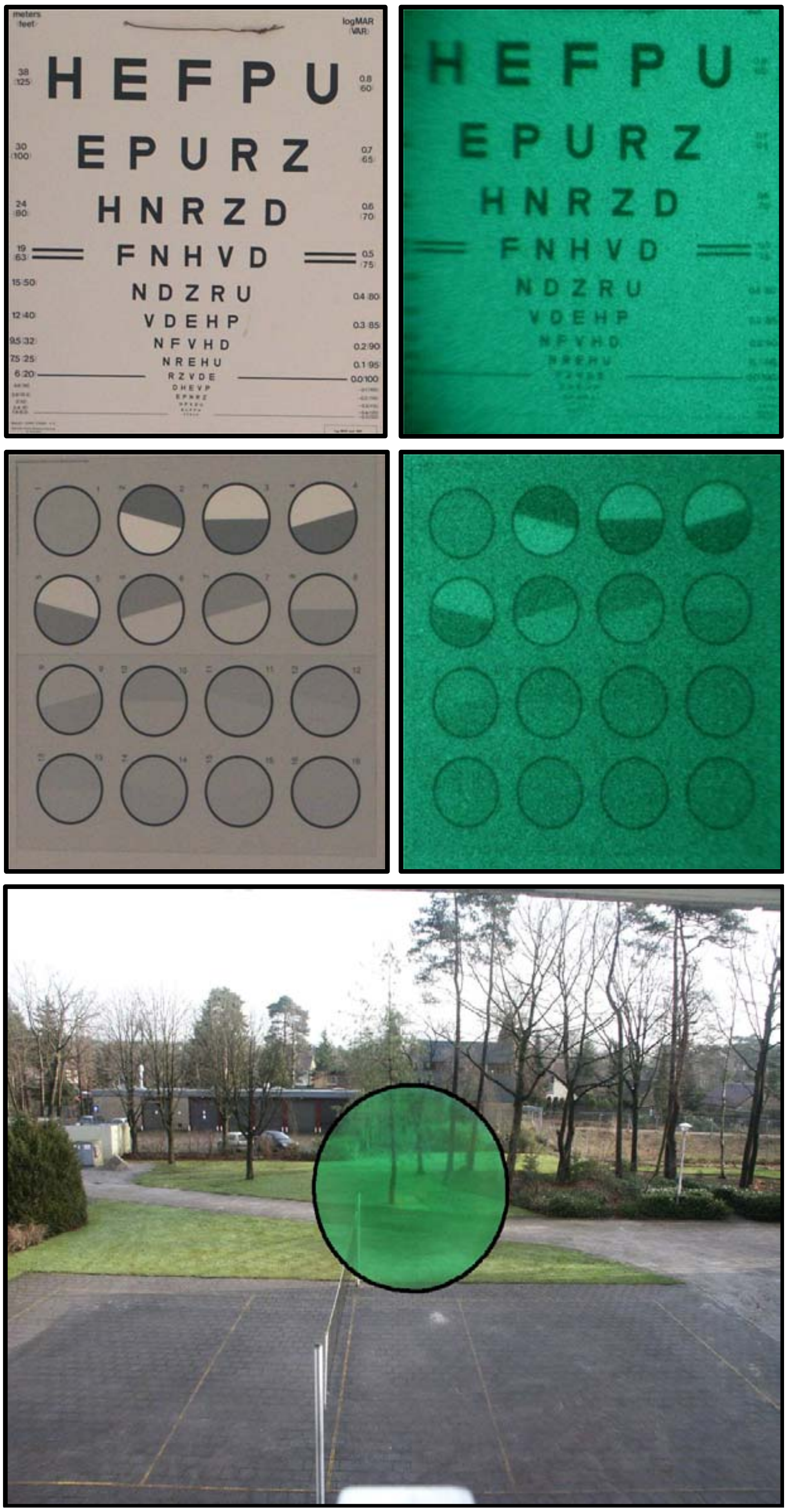

Figure 5.1: Visualization of the Degradation of Image Quality of a Modern NVG Relative to Normal Daylight Vision, without the Characteristic Photon Noise. Upper row: The naked eye in daytime can read 2 to 5 rows further down than the NVG aided eye on respectively clear and dark nights. Middle row: Daytime vision reaches to 4 to 8 times lower contrasts than NVG vision. Lower row: Field of view. The greenish inset represents the standard 40° NVG field-of-view, relative to the 180x120°field-of-view of the naked eye. A neutral density filter was used to register the intensified image during the day.

5.1.3 Terrain Board

A *terrain board* is suitable to demonstrate a variety of visual illusions, in particular to a helicopter crew. The terrain board provides a more active and a more realistic experience than the passive activity of watching videos or photos. Video's show how someone else must have experienced the world. The terrain board allows the student to experience the miniature world for himself. The didactic technique is to let the students misperceive a particular aspect and to uncover the misperception by themselves. Theoretical knowledge does not prevent the visual illusions. The terrain board therefore serves to confirm and accentuate the theoretical knowledge. It allows the students to actively look at the miniature world by changing viewing position, coming closer, or by changing the lighting conditions. Secondly the terrain board allows the student to experience the effects of NVG adjustment errors: some features become imperceptible while others remain unchanged. A well designed terrain board clearly shows all terrain features during (simulated) daylight, while many change appearance or disappear with NVGs. By changing the lighting conditions (moon phase and altitude, haziness) it is possible to demonstrate the various lighting effects. One instructor can simultaneously teach a group of students, whose common experience aids the learning process. A terrain board should include a variety of ground features (e.g. hills), a variety of terrain types (e.g. desert), presence of streetlights and extended cultural lighting, and objects containing the green chlorophyll.

5.1.4 Meteorological Demonstrations

The terrain board alone is not sufficient, particularly for F-16 pilots who typically fly at high altitudes. The primary visual effects that occur in the air are the unpredictable perception of meteorological conditions (e.g. haze) and of other aircraft. With simple means, one can develop a series of stand-alone demonstrations that each show one of the fundamental NVG visual limitations, in addition to the effects possible with a terrain board. Such demonstrations consist of physical objects whose geometry is easy to interpret with the naked eye in daylight but hard to interpret with an NVG and night-time illumination. The demonstrations have in common that the NVG percept deviates dramatically from the daytime view. In addition, the NVG percept is misleading while the scene during daylight is immediate and easy to interpret correctly. A questionnaire distributed among RNLAF Chinook flight personnel confirms the practical implications of the demonstrations illustrated here, in particular the lack of visibility in shadows, the lack of color, and the halos.

5.1.4.1 Spectral Density

One of the demonstrations concerns the *difference in spectral sensitivity* between the unaided eye and the NVG. The setup consists of five differently colored light emitting diodes, arranged according to the rainbow, from blue to green to yellow to orange to red (Figure 5.2). The NVG image is monochrome, showing all lights as green. The NVG is particularly sensitive to red light, also sensitive to near-IR light, and relatively insensitive to blue and green light.

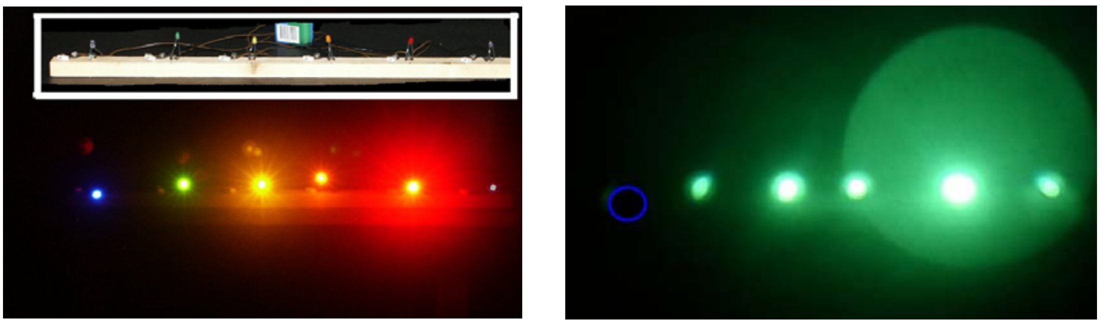

Figure 5.2: Effect of Lights with Different Colors.

5.1.4.2 Halos

Another demonstration is on the *absence of color and the occurrence of halos*. This demonstration employs a flickering light representative of an aircraft marking hangs in front of a projected scene of a lighted heliport at sea. The flickering light is easily visible with the unaided eye in daytime but hard to spot with the NVG at night. The absence of color, the glare due to the presence of halos, and the reduced visibility of temporal change in the NVG cause this difference. The perception of flicker is masked by the intrinsic noise of the image intensifier. When the observer moves sideways, the yellow marker distinguishes itself from the background by motion parallax and becomes easy to spot through the NVG.

5.1.4.3 False Perspective

The third demonstration is on how *halos and the dominance of light sources* can cause a dramatically distorted NVG depth perception. This can be shown by a wire frame to which several light sources have been attached (Figure 5.3). With the naked eye the correct geometry is apparent, but with the NVG the perceived geometry flips. When the observer moves sideways it appears as if the construction becomes fluid: the geometry distorts. The correct perspective does not re-appear as is usually the case with geometrical illusions. This demonstration is particularly powerful because the viewer cannot overcome the illusion even when he is aware of the correct geometry.

Figure 5.3: Line of Sight.

5.1.4.4 Shadows

The fourth demonstration is on the lack of NVG image quality in shadows. A scene represents a soldier standing just behind the opening of a doorway. The soldier can easily be seen with the unaided eye in daytime, but is almost invisible when seen with NVGs at night. The difference between black and dark grey disappears as a result of the poor contrast transfer of NVGs.

5.1.4.5 Reflections

A fifth demonstration concerns the effects of the high reflectivity of chlorophyll in the near-IR. During the day dark tree branches provide a strong contrast with the background reflecting the light of the sky and the sky itself. This obvious visual distinction disappears in the NVG image because the trees and background lack luminance as well as color contrast.

5.1.5 Conclusion

Summarizing, the purpose of these demonstrations is to show the main categories of illusions that occur with NVGs and are potentially hazardous to provoke SD. Stand-alone demonstrations can be easily deployed to train observers how to cope with the fundamental limitations of NVGs. Such stand-alone demonstrations can supplement the terrain boards.

5.2 SD TRAINING SCENARIOS FOR NIGHT VISION DEVICES

5.2.1 Helmet Mounted Systems Training, Ground-Based

Currently, there are no ground-based facilities for NVG training. A NVG simulator for training research has been developed by the Air Force Research Laboratory at Mesa AZ. This is a unique facility. It has been shown to be an effective tool for training aircrews to experience NVGs in a dynamic flight environment via visual simulation. This training offers pilots a unique flying experience on the ground. It is anticipated that these NVG simulators can be proliferated, especially at bases where the pilots are flying with NVGs.

It is anticipated Helmet Mounted Systems (HMSs) will become more and more common to the pilot as these technologies evolve. The head-up-display will be reproduced on the visor of the pilot in the next few years, eliminating the need to mount a glass-combiner on the fuselage of the aircraft. Attitude information will be displayed on the visor of the pilot and will be readily available regardless of where the pilot is looking. The obvious problem with this transition is the display of attitude information when the pilot is looking one direction while the aircraft's velocity vector is in another direction. This advancement will free the pilot from having to look at the HUD and then return his/her vision to a target of interest outside the cockpit. The problem is it adds another cognitive task by requiring the pilot to interpret a display that is not aligned with the aircraft's velocity vector. The final displays may be intuitive and simple to interpret when viewed off-axis. However, the new HMS will most likely require some ground-based training. Such training can be included in a ground-based simulator.

5.2.2 Night Vision Device Effects on Pilot Vision

It is indisputable that pilots flying while aided by night vision devices, such as night vision goggles (NVGs) and FLIR (forward-looking infrared), have enhanced the capability of military flight operations. Unlike unaided night flying during which flights are generally conducted at relatively higher altitudes and lower airspeeds, aided night flight has allowed aircrews to operate during low ambient light levels at terrain flight altitudes and at greater speeds. These advantages in night visual and operational capabilities, however, impose significant limitations to the aircrews' spatial orientation of which they must be aware [61].

Vision is considered the primary sense in orientation and is, therefore, vitally important to any aircraft operations. A pilot's ability to resist spatial disorientation is enhanced by adequate visual references [62]. Any factor that contributes to the degradation or reduction of normal day visual capability can be a contributor to SD. Specifically, aircraft accident research has shown that there is an increased risk of SD while flying with night vision devices [61]. Therefore, awareness of visual illusions and the limitations imposed by the use of these devices is necessary as a countermeasure to the SD hazard.

5.2.2.1 Visual Acuity

Depending on the model, the best acuity that can be expected from NVGs procured since 1996 is 20/25[1] [63]. This best acuity (or resolution) is achieved when the NVGs are used at the optimal sight adjustment point, under ideal environmental conditions, and when viewing high contrast targets. As conditions deteriorate, so does the acuity.

5.2.2.2 Limited Field of View (FOV)

Generally, most night vision goggles provide no more than 40-degrees FOV, both vertically and horizontally. This loss of peripheral vision may contribute to increase incidents of fixation (particularly

[1] Older goggles provide no better than 20/40, with 20/70 in the periphery of the field of view.

during landings) and to the loss of orienting visual cues such as motion parallax. Future generations of NVGs promise greater fields of view. Current prototypes provide 95 to 110 degrees [63].

5.2.2.3 Color Discrimination

Current NVG image intensifiers are monochromatic (single color). Most provide a green hue, but the color is dependent on the type of phosphor screen. This monochromatic scene reduces the ability to recognize contrasts of color, e.g., red lights on ground obstructions or aircraft.

5.2.2.4 Illumination

The performance of NVGs is directly related to the ambient light available. High ambient light (natural and cultural) improves resolution and therefore, objects can be identified at greater distances [64].

Moon illumination, phase and angle are the most important factors in NVG mission planning and flight operations. Caution should be taken to minimize the time flying directly into a rising or setting moon. The angle of the moon may have a positive or negative effect on the appearance of objects on the ground when viewed with NVGs. The moon at very low angles may distort the shape of terrain features while higher angles and high illumination levels can cause washout of terrain detail with a corresponding decrease of visual cues [65].

NVG gain automatically adjusts output brightness to a preset level to restrict peak display luminance. When an area with bright lights is viewed, the display luminance will dim. This is normal and is caused by the goggle's Bright Source Protection or its Automatic Brightness Control. The crewmember may experience this dimming effect, which results in a significant reduction in the resolution of the visual scene. Normal NVG function can immediately be regained by looking away from the light source.

Using landing lights and searchlights during periods of low illumination can cause an effect similar to tunnel vision. Peripheral orientation cues may be lost and fixation on the lighted "tunnel" may occur. During landings, apparent ground speed and rates of closure are difficult to judge [66] and crews may experience crater illusion.

Aircraft instrument lighting and supplemental cockpit lighting (flashlights, finger and lip lights, etc.), if not NVG compatible, may actually degrade the pilot's ability to see outside of the cockpit. Care should be taken to ensure that any lights used by the crew and/or passengers do not compromise NVG image intensification.

5.2.2.5 Weather Considerations

NVGs can see through light obstructions, such as light fog, rain, haze, or smoke. This capability increases the likelihood of inadvertently entering instrument meteorological conditions and possibly experiencing some type of SD. Increased moisture in the air can be detected by the inability to view the moon, stars or other light sources without the aid of goggles. Other indications include the lowering of the ambient light level, cloud shadows on the ground, and fog over water. As obscurations build, the NVGs will display increased video "noise" (scintillation) and decreased acuity [64]. A good indication that visibility restrictions are being encountered is the halo that forms around sources of illumination. If the halo becomes noticeably larger, visibility is deteriorating [66].

5.2.2.6 Depth Perception and Distance Estimation

Both depth perception and distance estimation are reduced while wearing NVGs. Depth perception in a given situation depends upon available light, type and quality of the goggles, degree of contrast in the field of view, and the viewer's experience [64]. In order to overcome these inherent difficulties in depth perception and distance estimation, aircrew knowledge of monocular and binocular cues is critical to maintaining spatial orientation.

5.2.2.7 Obstruction Detection

Obstructions that have poor reflective surfaces, such as wires and small tree limbs, are difficult, if not impossible, to detect [64]. Wires are difficult to detect with NVGs because of their small, circular reflective surfaces. Associating wires with man-made features will aid in detection. Watch for poles, long linear openings in wooded areas, or buildings in the middle of an open area. Comprehensive hazard map plotting and planning will help avoid these areas. Knowing your geographical position is essential [66].

5.2.2.8 Types of Surfaces

Operations over areas of limited contrast such as open grass- and asphalt/ concrete- covered areas, deserts, and water provide the NVG-aided aviator with additional challenges. Hovering flight maneuvers are particularly difficult due to the inability to correctly judge height and detect horizontal movement. Accurate estimation of height is nearly impossible without a radar altimeter. Frequently, in these areas of limited contrast, fixation on the few references available may cause SD. Pilots should avoid staring at a particular reference. Moving grass and water (waves) create the illusion of aircraft movement [66] and can contribute to SD and can cause incorrect, unnecessary, and dangerous control inputs.

5.2.3 Considerations and Strategies for Flying with NVGs

5.2.3.1 Considerations for Fixed-Wing Flight with NVGs

Compensation for the narrow FOV of NVGs is achieved by employing a constant, aggressive scan to enlarge the total field of regard. An effective scanning technique is essential for maintenance of good situational awareness and spatial orientation, including altitude awareness. For example, a dramatic loss of altitude awareness may occur if the scan is interrupted (e.g., if the neck is “splinted” during a high G maneuver). Experience has also shown that improving scan technique is one of the most effective methods for overcoming a misperception or illusion that has already occurred [66].

Additionally, proper preflight adjustment of the NVG is critical. Personal factors that could contribute to SD are low experience and inadequate currency in NVG flying, fatigue and other stressors. One must be prepared to transition to instrument flight at any time, and one therefore must maintain an aggressive instrument crosscheck complementary to the NVG scan. Aside from the potential SD traps common to anyone using NVGs, such as misperception of motion and distance cues, terrain contour or elevation, there are two SD traps that may be more important to aircrew in fast jets. Because of their operating airspeeds, changes in perception of scene flow can prove illusory. For example, transitioning from a cultural landscape to water, such as crossing a coastline, could give a sensation of a sudden deceleration in groundspeed or change in altitude. Another SD problem is unperceived flight into IMC, with concurrent loss of horizon signaled by only subtle cues in the NVG image such as a decrease in scene detail or increased scintillation.

Overcoming SD while using NVGs is no different than any other instance of SD. First, one must recognize the SD, with the immediate need to ascertain aircraft orientation by reference to the appropriate flight instruments. At the same time, the aviator must overcome the urge to maintain visual orientation using NVGs – the reason why SD occurred in the first place. The phase of flight is important, with more urgency at a very low altitude or during a rendezvous with another aircraft than when operating as a single ship at a medium altitude level. A prepared pilot will rehearse reactions to SD by knowing exactly what instruments to use for spatial orientation, how to coordinate with other crewmembers, and practicing different scenarios in a simulator. Safe execution of the mission is enhanced by knowledge and preparation, tempered by practice.

5.2.3.2 Considerations for Helicopter Terrain Flight with NVGs

This section concentrates on NOE operations including ground cushion maneuvers. It is strongly recommended that only helicopters equipped with a functional radar altimeter (preferably one with an audio low altitude warning alarm) be flown during NVG operations. An audio warning on the radar altimeter was the most frequently cited technological requirement to control the hazard of SD during military flight operations [6] and is considered by the authors to be a prerequisite for the effective maintenance of height awareness during rotary-wing NVG flight. Standard operating procedures should be developed and practiced using this device. A constant aggressive scanning technique [66] and good CRM are perhaps even more important for rotary-wing operations than they are for fixed-wing flight, because operations are conducted much closer to the ground and the margin for error is therefore less. An inadequate scanning technique and poor CRM were attributed to the genesis of 79.7% and 68.6%, respectively, of U.S. Army helicopter accidents [6].

5.2.3.3 Strategies for Safe Aided Night Flight

The following recommended strategies are primarily preventive, but suggestions on dealing with SD once it has been recognized are also given. Just as with daytime flight, NVG flight requires aircrew to perceive adequate visual cues in order to fly safely and effectively. Spatial disorientation occurring during rotary-wing NOE (nap-of-the-earth) flight with NVG is essentially due to a failure to acquire or recognize the visual cues that are essential to the maintenance of spatial orientation in the NOE environment.

Generally, the closer one is to the ground the better are the available visual cues, as long as they exist in the first place. Anticipation of a visually degraded environment, and thus the techniques that will be required to maintain orientation, is essential. A common problem is the failure to appreciate when there is little or no contrast or ground texture, two of the most "reliable" depth cues during NVG flight when close to the ground given that many of the 3-D visual cues are lost during NVG flight. The best advantage of the resulting 2-D environment must, therefore, be taken to prevent SD. For example, it would be reckless to plan an NVG approach to a single visual reference point in a snowfield. The crew should plan to follow known "solid" line features such as hedgerows rather than transit across open spaces with little or no orientation information available. In these circumstances it is also advisable in "side-by-side" helicopters for the pilot who is immediately adjacent to the feature to take control. Flying with NVGs is a skill that is easily lost and therefore, currency and competency are significant factors affecting orientation. The more skilled pilot should therefore undertake the more difficult task.

Although many NVG standard operating procedures allocate flight instrument monitoring duties (particularly speed and altitude) to the non-handling pilot, two pairs of eyes directed "outside" the cockpit are strongly advised in the final stages of the approach to land and during hovering maneuvers. The specific characteristics of an individual pair of NVGs and the external illumination conditions also contribute to SD. If the NVGs are not functioning properly, or if flight is planned for a particularly dark night, the pilot is already placing himself or herself at a disadvantage. The fixed-wing "lost wingman" procedure may be adopted during helicopter NVG flight at transit altitude. However, transit flights in helicopters are usually at a significantly lower altitude than fixed-wing flights and so, as the visual scene is more likely to be "cluttered" by terrain features, the technique of "sky-lining" the lead aircraft by slightly reducing altitude is a useful way for the wingman to maintain or regain his/her orientation within the formation.

When in NOE flight, military helicopters tend to operate as a single ship in a "group" and so the strategies for overcoming SD need only concern that particular aircraft (providing the pilot has a good situational awareness of the location of the other aircraft in the mission). As far as coping strategies are concerned, a handling pilot who loses visual should immediately inform the non-handling pilot. If the non-handling pilot has maintained visual references, he or she should take control immediately. If both pilots have lost visual references, the previously planned overshoot must be initiated. If solo, the pilot must initiate the previously planned overshoot without delay, based on lower threshold of "uncertainty" than in a two-seat aircraft. The majority of rotary-wing accidents and serious incidents that have arisen [6] suggest that aircrew did not appreciate the particular environmental and equipment limitations and subsequently failed to modify their visual scanning technique. The importance of maintaining excellent visual reference with the ground and neighboring obstacles at all times cannot be overstressed.

The Apache helicopter's Integrated Helmet And Display Sighting System (IHADSS) presents peculiar circumstances in that it incorporates a monocular display in which a visual image from a FLIR sensor is combined with flight and target acquisition symbology and presented to the pilot's right eye during night flight while vision in the left eye remains unaided. Once again, the emphasis must be upon avoidance of SD and most of the recommendations made in the NVG section are pertinent to flight using FLIR [66]. The primary advantage of the Apache IHADSS over the NVG is the inclusion of flight reference symbology (although symbology into NVGs has recently been introduced in some military aircraft). However, it must be noted that the scanning technique is both within the HMD (head mounted display) – moving the eye(s) around the display – as well as moving the eyes and head around the cockpit and external environment. Recovery from SD can therefore be assisted by this technology and it is possible (with appropriate training) to "control the aircraft to make the instruments read right" even during NOE and hovering flight. When HMDs are used in the modern Apache helicopters (U.S. Army AH-64D and the British Army's Apache AH Mk 1), recognized SD "coping" strategies once visual cues are lost at any stage of flight are as follows:

- Use the aircraft visible light source (landing lamp).
- Use the secondary FLIR sensor – there is both a FLIR pilot's night vision system (PNVS) and a Target Acquisition and Designation System (TADS), although the latter's resolution and lateral slew rate is not as good as the former.
- Hand over control to the other pilot.

If both aircrew have lost references, execute a recovery procedure. This is summarized as follows:

- Apply collective power to initiate a climb using the HMD's instrument reference;
- Declare to the other pilot that one is "executing a recovery procedure";
- Ensure that the climb is clear of obstacles;
- Select the flight page on the left-hand multi-purpose display so that the unaided left eye now has an instrument reference, while still using the HMD's instrument reference; and
- Change instrument reference from the HMD to the multi-purpose display flight page and continue as a "traditional" instrument recovery.

5.2.4 Conclusions

NVGs have certainly improved night flying capabilities, but along with the benefits come an increase in the risk of an SD experience. Awareness and knowledge of the limitations imposed by NVGs and the illusions one might encounter are critical to aviation operational safety. Training, proficiency and experience with the use of these devices is the key to the successful completion of an NVG mission.

Chapter 6 – OPTIMISATION OF SD TRAINING

6.1 INTRODUCTION

Research and technological initiatives that deal with SD will generally require a great deal of effort and financial resources to implement. This cannot be an argument to skip SD avoidance training, because this training is mandatory for flying training and continuation training for pilots according to STANAG 3114 (see Section 2.1, and [67]). However, training enhancements based on current knowledge and technology, where appropriate, can be more readily achieved and should therefore be addressed without delay. Ground-based training for student pilots should include lectures with improved quality of demonstrations and exposure to effective ground-based rotating devices, but avoiding amusement park types of demonstrations. Motion stimulus should not evoke symptoms of motion sickness. Although spatial disorientation avoidance training is targeted primarily for pilots, improved training for associated aviation personnel: flight surgeons, physiologist, aeromedical instructor/technicians, other aircrews such as loadmasters and search and rescue technicians would be ideal. This chapter attempts to provide some perspectives on the optimisation of training methods to minimize SD in NATO nations and to provide recommendations for interim and long-term training strategies.

6.2 ORGANISATION OF TRAINING

6.2.1 Timing of Training

Ab Initio (undergraduate) aircrew should first be provided with orientation training during the initial basic aeromedical course, which is commonly part of the undergraduate flying training program. If SD training is too far in advance of flight training, it may cause flight students to forget important material concerning SD before they may experience SD in flight. Training of any nature will be more effective if distributed over several sessions **when possible**. Therefore, a review of SD after primary flight training should be encouraged and emphasise the operational relevance of SD for that particular aircraft type. It is recommended that the initial block of spatial orientation training be retained at its present stage **(initial basic aeromedical training)**, but that short refresher blocks should be inserted before instrument flight training and during advanced flying training and before and during assignment to an operations training unit. It is also recommended that operational squadrons implement formal and standardized SD awareness training as part of the training syllabus for their specific type of aircraft. The instruction designed for individual aircrews by aircraft type should address the effects of that aircraft's flight characteristics and cockpit environment that could affect aircrew performance with respect to SD. For example:

a) List and discuss previous accidents and incidents, and the most probable situations to lead to SD occurrences in the specific aircraft type.

b) Discuss preventive measures, for example use ADI (Attitude Display Indicator), avoid After Burner (AB) take-off, and RT (Radio Transmission), etc.

c) Force student pilots into SD situations during in-flight training, for example, formation flying, ACM (Air Combat Manoeuvres), weather, etc.

d) Perform cockpit management training, employing radar altimeter descent profiles.

6.2.2 Instructional Techniques

A variety of pedagogical techniques should be employed in SD lectures and discussion according to the background and experience of the aircrew. The principal objective of instruction given on the ground is to provide factual knowledge about the sensory systems that are involved with spatial orientation and disorientation in flight. A formal approach is suitable for the teaching of pilot candidates and novice aircrew. This approach usually takes the form of didactic lectures supported by visual aids, such as slides, overhead transparencies, PowerPoint presentations, cine film or videotape. The length of the instruction would depend on the individual countries' capabilities and schedules. Examples of past mishaps where SD is a contributing factor will serve as ideal supplements. Personnel who have the appropriate theoretical background in physiology, psychophysics, familiarity with flight missions, aircraft, and possess an understanding of operations should present the classroom training. Scientists with operational research background play an important role in providing up-to-date information for the development of academic programs, interpreting the various types of disorientation to basic physiological and psychological mechanisms and serving as consultants to accident investigation. In this respect it is recommended that Flight Surgeons, Scientists, Physiologists and Aeromedical Technicians will be given more flight experience and will be provided with up-to-date teaching material. There is a need for a "feedback relationship" between the research and training communities, particularly if new and technologically advanced simulators or training materials are being considered. Some examples of such co-operation include avoiding the designation of a particular device solely for training or research, and including both trainers and researchers in device planning meetings. If the expert and best teachers in the air force were video-recorded giving their lectures, and these films distributed, then all training would be of enhanced quality. Availability of handouts with useful SD information for pilots is recommended (see Chapter 8).

The approach described above is suitable for the teaching of pilot candidates. However, informal group discussion about personal experiences and current hazards by type of aircraft led by experienced instructors, or flight surgeons who are also flight qualified, is most effective for the refresher training of established aviators who have "heard it before" The reasons are as follows: Established pilots are more likely to be attentive to accounts from their flying colleagues who learned about flying from disorientation incidents, or even accidents in which they had personal experience. A flight-qualified instructor will have an appreciation of what goes on in the cockpit, an in-depth understanding of the mission, and will know the type of disorientation likely to be experienced in the aircraft type. Such an instructor will have credibility with the students. Focus verbal training patterns on maintaining orientation awareness and disorientation prevention. This training should precede in-flight disorientation demonstrations, aerobatics and formation flight training with routine refresher training every 3 – 5 years. It is also emphasized that aviators receiving SD scenario training in Full Flight Simulators increased their situational awareness of the conditions and events that lead to SD. 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 (Section 3.5).

Having experienced pilots describe and discuss recurring SD situations that are specific to the aircraft type can improve SD awareness within the operational squadron. This awareness training should be made mandatory. Examples of the situations that most frequently lead to SD occurrences and corrective actions are summarized in Table 6.1.

Table 6.1: Examples of Situations that have Caused SD Incidents or Accidents

Situations	Cause and/or Preventive Measures
1) Take-off with after-burner at night and/or weather conditions (somatogravic illusion)	i) ADI (Attitude Display Indicator) must be up on the DDI (Digital Display Indicator) for take-off into weather/night meteorological conditions. ii) AB is only used when absolutely necessary.
2) Flying in formation	Leans are easily experienced when flying as wingman at night or in weather / white-out conditions. Breaking in and out of cloud can also be very disorienting, especially on the wing: i) Flying with the ADI up on the DDI that is on the lead's side can be included in the crosscheck to overcome SD tendencies. ii) Make sure lights are properly adjusted on the lead aircraft, because improperly adjusted lights on the lead aircraft will also cause problems at night.
3) Air Combat Manoeuvring	Three-dimensional manoeuvring in tactics such as rolling scissors can cause SD particularly in the "soup bowl" weather conditions. i) In order to keep orientation, the pilot must have a distinct horizon to refer to at least in his peripheral vision.
4) Instrument Fixation / Channelised Attention	Channelised attention, e.g. on the radar or the velocity vector frozen in the HUD will lead to situations of SD or potential unusual attitudes. i) A continuous and rapid cross check of interdependent instruments will avoid these situations.
5) Target Fixation / Loss of Depth Perception	Fixation on rejoins with excessive overtake have caused mid-air collisions. Fixating with aiming systems for weapons solutions on ground or air targets could cause pilots to lose depth perception. i) These risk factors can be reduced by spatial orientation awareness training and performance of frequent crosschecks.
6) Meteorological Conditions	Stars can look the same as the ground over the prairies and in extreme latitudes. Flying over water, especially glassy surface can cause depth perception problems. Flying during whiteout can cause the disappearance of the horizon.
7) Emergency pull up	Sense of excess of pitch up during the initial phase of an emergency pull up procedure.
8) Entering IMC conditions	Sudden entering in IMC often induces a loss of the correct sense of attitude.
9) Refueling from side baskets of tanker aircraft	Refueling from side baskets of tankers having tilted wings during flight (e.g. ITAF Boeing 707) usually induces a sense of false horizon.

6.2.3 Training Assessment

It is recommended that air forces determine a method of evaluation of the training effectiveness of the ground-based and/or in-flight SD demonstration. An assessment of the retention of aeromedical knowledge in SD would also be valuable. Much of what students learned about SD is not formally tested and therefore may not receive the attention it deserves. SD should be explicitly included not only as part of crew coordination training and situation awareness training, but also during the mission risk analysis when planning specific missions. Poor crew coordination has been cited as a factor leading to an increased risk of SD in many aircraft accidents [68].

6.3 TYPES OF TRAINING

6.3.1 Ground-Based SD Demonstration and Training

Ground-based **demonstration** is defined as the demonstration of the limitations of the orientation senses in a demonstration device or flight simulator. Essentially, this comprises further reinforcement of classroom instruction and is best conducted with groups of students by an aeromedical professional (flight surgeon, physiologist). Ground-based **training** is defined as learning and then demonstrating competence in handling simulated in-flight disorientating circumstances and illusions, e.g. recovery from unusual attitudes and procedures for inadvertent entry to instrument meteorological conditions (IMC). This is the responsibility of flight instructors (who have themselves been appropriately trained to teach the procedures and to assess competence).

A demonstration of the limitations of the orientation senses is an essential part of initial and refresher aeromedical training. As shown in Chapter 2 most NATO countries perform some form of demonstration using many different types of ground-based devices (e.g. Barany chair and multi-axis electromechanical devices). The Barany chair is probably an adequate introductory tool and should be used to demonstrate the perceptual threshold and limitation of rotation sensations, the somatogyral illusion about the yaw axis, the Coriolis Effect and the demonstration of the vestibulo-ocular reflex, which causes a loss of dynamic visual acuity due to nystagmus (see Table 6.2). As many students as possible should experience these basic vestibular and visual phenomena. In addition, other laboratory devices such as off-vertical axis rotation chair, optokinetic drum and other devices can be used to demonstrate the limitations and inadequacies of our sensory systems in maintaining orientation. The demonstration should be followed by a simple explanation based on the physiology and psychophysics that were taught. More details for a number of those vestibular and visual illusions are described in Section 3.2. This part is essential because it provides the building bricks for understanding the in-flight illusions.

Table 6.2: Barany Chair (Category 1) Ground-Based SD Demonstration

Illusion/limitation of Senses	Type	Initial Training		Refresher Training	
		Essential	Desirable	Essential	Desirable
Somatogyral	Vestibular	√		√	
Decrease of Visual Acuity (Vestibulo Ocular Reflex	Vestibular-Visual	√			√
Oculogyral	Vestibular-Visual	√			√
Rotation Thresholds	Vestibular	√		√	
Coriolis	Vestibular-(Visual)	√			√

There is definitely a role for dedicated SD demonstration and training devices. Experiencing disorientation is a training condition that should be an aspect of IFR proficiency training. Disorientation training should occur in a flight simulation environment, within the context of a realistic flying task that contributes to IFR proficiency. An effective ground-based closed-loop trainer must be realistic and provide aircrew with an opportunity to “fly through” the disorientation or control and recover the trainer. This follow-up of the basic SD demonstration is described in detail in Chapter 3.3 and 3.4. It is obvious that some flying skills are required for the student pilots to control these flight simulator devices.

Ideally, in order to enhance ground-based demonstration and training, the sensations induced by the simulator must be isomorphic (of the same form or equivalent to the sensations felt during the real flight profile being simulated.) They should also be isomorphic to the coordinated subconscious reactions elicited from various sensory-motor systems during an actual flight. However, the flight envelope cannot be reproduced on the ground; it is therefore imperative that the objectives and limitations of any ground-based demonstration and training be explained fully to the trainees. The training application of these devices requires careful consideration, not only in terms of who is exposed, but also in the nature of the demonstrations (Sections 3.3 and 3.4). Research laboratories are in an excellent position to guide the choice of training tools and to suggest ways for implementation to achieve the final goals (See also Section 6.3.4.3, and [31]).

6.3.1.1 What Illusions Should be Demonstrated

As it is unrealistic to suggest that all pilots should experience all illusions, specific in-flight illusions should be defined as either essential or desirable. Essential illusion demonstrations are those that all pilots should experience or witness. Desirable illusions are those that are not essential but are considered worthwhile for the pilot to experience.

The ASCC Air Standard 61/117/14 is in this respect of interest since this standard suggests which illusions are considered to be essential to incorporate in the demonstration and which illusions are desirable (Table 6.3 for RW and Table 6.4 for FW aircraft): The more so since this standard is incorporated in the draft version of Edition 8 of STANAG 3114 (see Section 2.1).

Table 6.3: Rotary-Wing Aircraft Ground-Based SD Demonstration

Illusion/limitation of Senses	Type	Demonstration Device Category	Initial Training		Refresher Training	
			Essential	Desirable	Essential	Desirable
The Leans	Vestibular	2, 3, 4	√		√	
Somatogyral	Vestibular	2, 3, 4	√		√	
Oculogyral	Visual-Vestibular	1, 2, 3, 4	√			√
Coriolis	Vestibular	1, 2, 3, 4		√		√
Autokinesis	Visual	2, 3, 4	√		√	
Size constancy (Runway width)	Visual	2, 3, 4	√			√
Shape constancy (Runway upslope)	Visual	2, 3, 4	√			√
Vection illusion	Visual	2, 3, 4		√		√
False sensation of rotation	Vestibular	1, 2, 3, 4	√			√

Table 6.4: Fixed-Wing Aircraft Ground-Based SD Demonstration

Illusion/limitation of senses	Type	Demonstration Device Category	Initial Training		Refresher Training	
			Essential	Desirable	Essential	Desirable
The Leans	Vestibular	2, 3, 4	√		√	
Spin Recovery (Somatogyral)	Vestibular	2, 3, 4	√		√	
Graveyard Spiral	Vestibular	4				√
Oculogyral	Visual-Vestibular	1, 2, 3, 4	√			√
Somatogravic	Vestibular	2, 3, 4		√		√
Oculogravic	Visual-Vestibular	3, 4		√		√
Coriolis	Vestibular	1, 2, 3, 4	√			
G- Excess	Vestibular	4		√		√
Autokinesis	Visual	2, 3, 4	√			√
Size constancy (Runway width)	Visual	2, 3, 4	√			√
Shape constancy (Runway upslope)	Visual	2, 3, 4	√			√
Black-hole landing	Visual	2, 3, 4	√			√
False sensation of rotation	Vestibular	1, 2, 3, 4	√			√

It should be noted that in the terms of Chapter 3, some of these illusions could be demonstrated better during the Demonstration of Basic Visual and Vestibular Illusions (Section 3.3) than during the Ground-based Training of In-flight Illusions (Section 3.4). The Task Group favours the demonstration of the basic visual and vestibular illusions before the student pilots are confronted with the in-flight illusions, to make sure that they have some understanding of why these illusions happen, and that these illusions are not emerging out of the blue, which should be frightening.

It is also recognized that there is substantial benefit to be gained from pilots observing their peers experiencing the illusions on the demonstration device. This will allow the students to realize that there are individual differences in susceptibility and level of response. With devices of category 2, 3 and 4 (Table 3.1) special effects are used to induce the SD illusions: this requires some explanation to the subjects watching the demonstration. Air Forces should ensure that each pilot will personally experience at least one visual illusion and one vestibular illusion and witness others undergoing the demonstration. Training objectives for both initial and refresher training should reflect this training.

AIR STD 61/117/14 [31] also suggests a number of factors that should be considered when choosing which limitations of spatial orientation or illusions to demonstrate to aircrew:

1) The effectiveness of the device at producing/reproducing the illusion without inducing negative transfer of training should be investigated. A flight surgeon or SD training instructor

(e.g. physiologist) should confirm the effectiveness of a particular device to demonstrate the illusion (see also Section 3.4.3.6).

2) The illusions demonstrated should be operationally relevant. For example, the graveyard spiral is not commonly encountered in rotary-wing flying. Therefore, there is little to be achieved by the demonstration of this illusion to a helicopter pilot.

3) Consideration should also be given to demonstrating illusions at a time that is of relevant to the stage of flying training, e.g. demonstrating autokinesis before initial night flying training.

4) Some limitations/illusions (e.g. "the Leans") can be demonstrated effectively during an in-flight demonstration. Therefore, if an air force has this capability, it adds to the demonstration on the ground.

5) The role of distraction should be emphasized because the generation of some illusions may be "enhanced" by the incorporation of a simultaneous distracting task. This will also stress the operational importance of distraction in the generation of SD in flight.

6) Flight training and experimental simulators may be used as SD demonstration devices where appropriate. The idea of using existing flight simulators for SD familiarization training was explored through a collaborative contract [69]. One of the major findings indicated that illusory self-motion and self-tilt in a flight simulator should not require a motion base when the visual scene contains features that will provide an up-down orientation. This is likely to be the case during take-off and landing. In other words, we could use existing non-motion based or motion based operational flight simulator, as discussed in Section 3.5, to demonstrate and teach pilots to cope with some of the visual illusions that one might encounter during take-off and landing. As discussed in Chapter 3.5 NATO Air Forces should examine the benefits of incorporation of SD training into present and future flight training simulators. Both motion- and fixed-base simulators should be considered to demonstrate SD situations, and to safely train students in SD avoidance and recovery procedures. Specific scenarios derived from accident sequences would be valuable for the student to obtain direct experience in preventing and overcoming SD in a realistic setting. See for this argument also Section 3.5.4 (Usefulness of Full Flight Simulators for SD Training).

6.3.1.2 Eye Tracking / Visual Scan Training for Refresher Courses

Pilot flight proficiency is an erodable skill. The critical flight proficiency requirement is to maintain control of the aircraft despite disorientation. In addition, channelized attention has long been recognized as a central etiological error for SD. In this case, when under stress or when disoriented, a pilot attempts to perform a demanding or unfamiliar task, and allows his attention to be confined to one aspect of the task; he/she therefore fails to make optimum use of information about the aircraft orientation. This limitation is a normal behavioural response to the physical and mental load imposed by the mission profile. For example, SD and target fixation is a hazard during weapons delivery. Current development of visual scan monitoring technology has demonstrated that the technology could be applied in combating channelised attention [70,71,72,73]. As mentioned above, disorientation training should contribute to IFR proficiency. Visual scanning technology should be employed in active training squadrons to demonstrate correct and effective crosscheck procedures and outcomes, to provide immediate feedback to student pilots with a real time performance record, and to establish and reinforce habit pattern and enable immediate intervention to correct faulty patterns during ground-based training. Task demonstration and immediate feedback have been shown to improve the speed and quality of training [74].

6.3.2 SD In-Flight Demonstration and Training

It has been shown that demonstrations of SD within the actual flight environment are extremely valuable [75] and are complementary to the ground-based didactic lectures and demonstrations. In addition, there is a distinct difference between in-flight demonstrations of SD, and training to overcome the problem once it has occurred. SD demonstration in flight consists of reinforcement of the limitations of the orientation senses in flight, and the enhancement of aircrew awareness to potential SD situations. On the other hand, SD training consists of a series of flight procedures to cope with disorientating circumstances and illusions. Since the British Army instituted its in-flight demonstration program (British Army SD Demonstration Sortie), their SD mishaps have decreased by 50% [75]. It appears that the most meaningful way to train aircrew to recognize and overcome SD in flight is to conduct SD in-flight training. A formal program of in-flight spatial orientation training, particularly with more emphasis on unrecognized SD (Type I) needs to be implemented. The availability of flight time may limit the conduct of SD demonstration and training. However, pilots and instructors could utilize the time made available on their way to mission sites (see also Section 4.3 In-flight SD Training Scenarios).

The current practice of recovering from unusual attitudes and related eye-closed manoeuvres is valuable. However, an enhancement to these procedures would be to routinely allow the student to enter an unusual attitude and then recover from it. This is in addition to the more traditional method wherein the instructor pilot places the student into an unusual attitude. However, rigorous conditioning should be avoided, because of the possibility of transferring negative learning to flying the aircraft. For example, the large gaze shifts and large head movements performed while transferring attention between cockpit and target aircraft could introduce a combination of cross-coupled accelerations and G-excess effects, either of which could induce nausea in some subjects. When head movements are disconcerting to a pilot due to a combination of G-excess and cross-coupled stimulation, the pilot will tend to avoid or minimize the motion-generated stimulus by making smaller head movements with larger deviation of gaze. Such movements are not necessary in the aircraft environment where the cross-coupled effects are reduced due to the large turning radius and, thus, reduced angular velocity.

6.4 SOME PRACTICAL RECOMMENDATIONS FOR AIRCREW TO IMPROVE SD AWARENESS

1) Look for potential human performance problem areas prior to and during missions. Prioritize tasks to avoid and manage the anticipated problems [67]. The reasons are as follows:
   - The mental functions involved in maintaining appropriate flight control involve more than processing of orientation sensory inputs. Task saturation, channelised attention, distraction and other factors have been identified as affecting mental processes contributing to mishaps.
   - Understanding how mental processing takes place helps the aviator to understand how even the most competent pilot may lose true awareness of flight conditions.
   - Knowing the flight conditions, which can introduce erroneous perception of aircraft attitude, might alert the Pilot to avoid those conditions.
   - Identifying traps and conveying appropriate knowledge to deal with insidious, unavoidable threats to safety.

2) Pilots are often told to “Believe your instruments.” However, it is important to be sure that the pilot does not simply indulge in an attempt at belief of perception when disoriented. Pilots should be told that, in case of disorientation, “Control the aircraft to make the instruments read what you want them to.” [76].

3) Realize that a pilot’s instructions about what to do in case of disorientation can be useful only in the case of recognized disorientation. Unrecognised disorientation can be dealt with by avoiding situations that are prone to induce disorientation. Aircrew should be taught to recognize conditions, which can be traps to a loss of orientation.

4) Avoid unrecognised disorientation by being aware of the flight conditions with which it is most associated:

- Avoid approaches over non-illuminated terrain, over smooth snow, or calm sea and take into account the possibility of facilitating circumstances, as cloud layers merging with sea fog, false sky effects and others.
- Avoid head movements under conditions greater than 1G (although this is impractical during operational flying, the awareness of the potential of G-excess effect on orientation is noteworthy).
- Avoid removing the gaze from flight instruments when in cloud and maintain crosscheck.
- Abstain from drinking alcohol for 24 hours before flying. Alcohol produces a light (low density) spot that changes location in the semicircular canal during the post-ingestion decrease of the blood alcohol concentration. This light spot predisposes pilots to disorientation and it persists for up to 34 hours after drinking [77].

5) Pilots should be aware that sometimes disorientation is misperceived as a failure in the flight instruments, such as in the artificial horizon, or a failure in an aircraft control system. Therefore, when a failure in a flight instrument or in the control system is "suspected", the pilot must verify the correct diagnosis of the problem before reacting.

6) Lastly, problems of disorientation can sometimes be solved by using the autopilot or by passing control to another pilot (when available) who is not disoriented.

Chapter 7 – INSTRUCTORS

7.1 INTRODUCTION

The objective of this chapter is to provide some practical guidelines to the instructors who are involved in aeromedical and physiological training on countermeasures to spatial disorientation (SD). The role of the instructors, who are responsible for the theoretical explanation of SD and the technical supports, and who conduct the practical exercises on SD, is defined. We will begin by identifying the qualifications that are needed to perform SD training on aircrews. This will be followed by general guidelines in the development of optimal strategies at different stages of the training program.

As stated in the preceding Chapter 6 (Optimisation of SD training), it is possible to categorise SD training in at least two consecutive phases.

- Basic training in spatial orientation: aiming to provide student pilots with basic information on the physiological and psychological factors involving spatial orientation and disorientation.
- Advanced training or refresher training at the operational squadron level: aiming to provide pilots with a brief review on the SD phenomenon with emphasis on the application of SD countermeasures during operational scenarios.

Instructors involved in these two phases of SD training will consequently have to possess different theoretical and practical background in order to use different approaches.

7.2 PERSONNEL

During basic training in spatial orientation, a strict correlation and explanation between the anatomy and physiology of human sensory systems and some of the corresponding illusions is mandatory. Moreover, practical clinical examples of the function and malfunction of our sensory systems would be helpful, to explain our responses to altered sensory inputs. In addition, different types of illusions from the standard neuro-psychological practice can evoke interest in the trainees, even if they are not strictly related to flight operations. Therefore, instructors with a biomedical background would be suitable to conduct this training phase, for example, flight surgeons, flight physiologists and neuro-psychologists. On the other hand, examples and explanations given in relation to flight operations should be limited to simple situations, because of the trainees' lack of flight experience. For this reason, the instructor's knowledge background in flying may not have to be extensive; however, knowledge of epidemiological studies on the causes of flight mishaps in military and civil aviation could serve as a useful introduction to the more detailed information on specific illusions (cf. data in previous chapters, and [5]). It is desirable for instructors with biomedical background to gain flight experience and have a direct contact with operational flight squadrons.

As cited in Chapter 6 on SD Training Optimization, this early part of the training on SD can further be divided into several steps; in accordance with the progression of flight activity and experience (e.g. only introduce certain illusions when night time flight activity is undertaken). Cognitive processes underlying orientation and disorientation are an important concept for the advanced course, where situational awareness plays a prominent and understandable role. Therefore, instructors with background and experience in flight activities (i.e. pilots, navigators) or experience in the management of situation awareness (e.g. euro-psychologists) are appropriate. However, these instructors should possess sufficient knowledge of the physiology of the sensory systems as applied to flight. The Aerospace Physiologist certification is one of the possible alternatives that can provide sufficient theoretical background in these professional areas. Previous flight experience on the part of instructors will also facilitate a familiarization with trainees and also the use of an adequate flight terminology.

The practical part of the training program requires dedicated technical personnel, particularly skilled in the use of the SD training devices in the respective laboratories and training centres. This is extremely helpful in fostering a confidential relationship between program instructors and student pilots. Therefore, in selected cases where technicians have a sufficient theoretical background, as in the case of Flight Physiology certified personnel, they can assume primary responsibility. In such cases, the inclusion of the theoretical explanation of the various SD phenomena demonstrated by the various devices would be advantageous. The mechanism of spatial orientation and disorientation can either be disseminated prior to, simultaneously, or in some cases, after the practical demonstration and hands-on training. The following Table 7.1 summarises the role of each professional background during the various training steps.

Table 7.1: Personnel Suggested for Basic and Advanced SD Courses

	Basic	**Advanced**
Physicians, Flight Surgeons	Suggested	Not required
Pilots/Navigators	Not required	Suggested
Physiologists and Neuro-Psychologists	Not required	Suggested
Technicians	Suggested	Suggested

It is of utmost importance that the stimuli employed in the training do not induce severe discomfort such as nausea and vomiting for the trainees in order to maintain an acceptable level of interest, to avoid negative influence on the observers and to allow the trainee to proceed to the next level of the program. If flight simulators are used to illustrate some forms of SD illusions, it is essential that the instructors provide detailed explanation of the mechanisms employed by these simulators to re-create the illusion. Also a distinction should be made between simulated and actual flight scenarios so that the lack of realism in a simulator does not compromise the training outcome. In addition, exercise in flight simulators should follow those using other laboratory tools (e.g. Barany chair, off-axis rotatory chair, and others), so that the physiological mechanism underlying the illusion can be understood and experienced by the observers and the trainee.

Different characteristics of the training activity will depend on the instructors' professional background, and are summarized as follows:

7.2.1 Flight Surgeons, Physicians (In General, Instructors with a Life Science Background)

Their task is to provide simple and accurate information about the physiology of the different sensory organs involved in spatial orientation. During the lesson, practical examples should be given, including some clinical aspects of sensory dysfunction and intra-sensory conflicts. Moreover, the easy-to-understand physiological basis of simple illusion will be given during the basic course. The appropriate use of aeronautical or aerodynamic terms will be helpful in creating a good rapport with the trainees and enhance communication, especially when the physician is dealing with the more experienced aircrews in the advanced training phase. The major technical characteristics of modern aircraft cockpits (e.g. NVG use or infrared systems) should be part of the instructor's knowledge, due to the influence of these systems on flight and health safety issues.

7.2.2 Pilots/Navigators

This category of instructor does not require significant updates about aeronautical terminology or in-flight systems. On the other hand, an insight on aeromedical physiology and/or psychology is absolutely necessary. The “aerospace physiologist” certification, although strictly required for this category of trainer, is not *per se* sufficient to assume that they have adequate knowledge regarding SD instruction. Therefore, dedicated training in the SD phenomenon together with a sufficient period of on-the-job training will be essential. This category of instructors would be extremely desirable if advanced disorientation profiles are simulated within a Full Flight Simulator (e.g. to re-create scenarios where SD mishaps occurred, or to conduct the training into particular simulated situations, see also Section 3.5).

7.2.3 Neurophysiologists/Neuropsychologists

Many neuropsychological factors play a role in SD mishaps. Therefore, the modern approach to the cognitive/psychological aspects of SD must be emphasised, specifically in advanced orientation training programs. Such a factor implies that selection of specialized personnel with human neuropsychological behaviour background can contribute to the training program.

7.2.4 Technical Personnel

The various laboratory tools, especially the ones with advanced level of sophistication and of instrument complexity, (for example, state-of-the-art flight simulators) require dedicated technical personnel who are familiar with the operation and general maintenance of these devises. As mentioned above, these personnel, with proper certification such as the Aerospace Physiologist certification, can assume responsibility of part of the training, under the supervision of more qualified personnel. However, their participation should be limited to the practical exercise.

7.3 CERTIFICATION

Finally, the Aerospace Physiologists certification is an important qualification that usually ensures adequate knowledge on several aeromedical aspects of flight. SD is one of the topics to be covered during this course, together with hypoxia, human response to acceleration and others. The course usually lasts a few weeks and is excellent for the purposes of general aeromedical physiology training. However, it is normally not sufficient to gain an in-depth understanding of spatial orientation and SD countermeasures training. We recommend that Aerospace Physiologist certification course will suffice as the basic preparation (especially for non-medical instructors) but that it should be followed by appropriate practical experience in the training centre for spatial orientation.

Chapter 8 – AIRCREW HANDOUT (EXAMPLE)

8.1 INTRODUCTION

Student pilots and experienced pilots as well as aircrew in general are encouraged to read articles covering SD issues in Flight Safety Magazines. Flight safety departments are encouraged to report on SD incidents and accidents on a regular basis in these magazines and on so-called flight safety days.

The availability of Handouts for aircrew after the SD demonstrations makes sense; the completeness of the SD information may vary. We may not expect aircrew to read the very complete book "Spatial Disorientation in Aviation", Eds. Previc FH & Ercoline WR (2004) [26]. The Chapter entitled "Spatial Disorientation: perception in the Aviation Environment" from the Aviation Medicine Handbook written by Braithwaite (2002) [78] provides excellent, more aircrew tailored information and may be read by aircrew.

In the following sections the text and lay-out for a short SD Handout for aircrew is given.

8.2 TEXT FOR SD HANDOUT

8.2.1 Definitions

Having **Situational Awareness (SA)** means that you:

- Are spatially and geographically oriented;
- Have a good perception and appreciation of your tactical environment; and
- Have a good appreciation of factors that are important in keeping the aircraft (AC) safe from hazardous situations or potentially dangerous flight paths.

Your **Spatial Orientation** is maintained correctly by:

- Integrating the information from your vision and from your vestibular, joint and pressure receptors; and
- Together with information from AC instruments and displays.

You have **Spatial Disorientation (SD)** when:

- You fail to experience correctly the position, motion or attitude of your AC in relation to the surface of the ground or to other AC.

SD Classification

SD is usually divided into **"unrecognized SD" (Type I)** or **"recognized SD" (Type II).**

Rarely Type II SD develops into an **"incapacitating SD" (Type III)** associated with a high degree of acute anxiety or fear.

8.2.2 Sensory Organs

Your **Sensory organs** are not perfect for flying purposes:

- But your vision is far better than your vestibular organs.

- Erroneous or inadequate information from your sensory organs to your brain gives rise to **an *input error***.

Your **Vision:**

- ***Focal vision*** is used for object and colour recognition and identification (e.g. reading). Information is processed in higher brain levels (time consuming).
- ***Peripheral vision*** is for orientation and movement recognition and night vision. Information is often processed on a subconscious level (time sparing).

Your **Vestibular Apparatus**:

- ***Semicircular canals*** detects angular accelerations as low as $0.5°/s^2$.
- ***Otolith organs*** (saccule and utricle) detect linear accelerations in all directions as low as 0.01G ($G=9.81m/s^2$).

8.2.3 Brain Function

Your *Brain* may sometimes not work optimally:

- Reliable sensory or instrument information about AC orientation is foreseen.
- Physical or mental stress as well as complacency give rise to a *central error.*

8.2.4 Most Common SDs

Gravic Illusions:

- Illusions during a ***stable state of G-forces*** with a false perception of AC attitude.
- Illusions without visual cues are termed ***somatogravic***.
- Illusions with visual cues are termed ***oculogravic*.**

Somatogravic Examples:

- Coordinated stable turn feels like flying level (no bank).
- Stable acceleration or deceleration feels like climb or descent.

Oculogravic Examples:

- Ill-defined horizon fools you to fly with one wing low ("the leans").
- Bad weather w/wo rain, snowfall or different kinds of lights give you a false impression of speed or AC attitude.
- NB: Oculogravic illusions are the most common subset of illusions in flight!.

Gyral Illusions:

- Illusions during a ***change of G-forces*** with a false perception of AC turn.
- Illusions without visual cues are termed **somatogyral**.
- Illusions with visual cues are termed **oculogyral**.

Somatogyral Example:

- Recovery from a coordinated turn, roll or a spin feels like entering a manoeuvre in the opposite direction.

Oculogyral Example:

- AC movements affects the visual perception, giving rise to nystagmic eye movements which gives error in localization and motion of visual targets.

The illusions or input errors outlined above create SD which can be of either Type I or Type II, occasionally also developing into Type III.

Central errors create Type I SD and are the most dangerous type of SD since the pilot for different reasons doesn’t use given reliable information of AC flight parameters.

Examples:

- Coning of attention or “target fascination”;
- Error of expectancy;
- Mental stress;
- Complacency; and
- Environmental factors like hypoxia, high-G or disease.

8.2.5 Factors Linked to SD

Flight Environment:

- VFR/IFR transition;
- Isolated lights, bad visibility;
- High altitude, low dynamic light flow input (peripheral vision); and
- Featureless terrain (peripheral vision).

Flight Manoeuvres:

- Prolonged acceleration/deceleration (-gravic illusions);
- Recovery from prolonged turns (-gyral illusions);
- Subthreshold changes of AC flight parameters; and
- Ascent or descent pressure vertigo.

AC Factors:

- Bad instruments (small HUDs, bad location in cockpit);
- Bad symbology;
- View from cockpit (visual frame of reference, “break-off” risk); and
- High manoeuvrability (angular and linear accelerations).

Aircrew Factors:

- Flight experience;
- Training in instrument flights;
- Currency of flying;
- Physical health;

- Alcohol and drugs;
- Fatigue or task stress; and
- Cognitive factors like attention, operational qualification, anxiety.

8.3 EXAMPLE OF SINGLE SHEET SD HANDOUT

In Figure 8.1 and Figure 8.2 it is shown how this text may be used for a one-sheet handout. Aeromedical Institutes can add their logo and improve the layout to make it acceptable and fancy for the target population.

SD Handout

Definitions

Having **Situational Awareness (SA)** means that you

- are spatially and geographically oriented
- have a good perception and appreciation of your tactical environment
- have a good appreciation of factors that are important in keeping the aircraft (AC) safe from hazardous situations or potentially dangerous flight paths.

Your **Spatial Orientation** is maintained correctly by

- integrating the information from your vision and from your vestibular, joint and pressure receptors
- together with information from AC instruments and displays.

You have **Spatial Disorientation (SD)** when

- you fail to experience correctly the position, motion or attitude of your AC in relation to the surface of the ground or to other AC

SD classification

SD is usually divided into **"unrecognized SD" (Type I)** or **"recognized SD" (Type II)**.

Rarely Type II SD develops into an **"incapacitating SD" (Type III)** associated with a high degree of acute anxiety or fear.

1

Sensory organs

Your **Sensory organs** are not perfect for flying purposes.

- But your vision is far better than your vestibular organs
- Erroneous or inadequate information from your sensory organs to your brain gives rise to **an *input error*.**

Your **Vision**

- ***Focal vision*** is used for object and colour recognition and identification (e.g. reading). Information is processed in higher brain levels (time consuming).
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Your **Vestibular apparatus**

- ***Semicircular canals*** detect angular accelerations as low as 0.5°/s²
- ***Otolith organs*** (saccule and utricle) detect linear accelerations in all directions as low as 0.01G (G=9.81m/s²).

Brain function

Your **Brain** may sometimes not work optimally

- Reliable sensory or instrument information about AC orientation is foreseen
- Physical or mental stress as well as complacency give rise to a **central error**

2

Most common SDs

-gravic illusions

- Illusions during a ***stable state of G-forces*** with a false perception of AC attitude.
- Illusions without visual cues are termed **somatogravic**
- Illusions with visual cues are termed **oculogravic**

Somatogravic examples:

- Coordinated stable turn feels like flying level (no bank).
- Stable acceleration or deceleration feels like climb or descent.

Oculogravic examples:

- Ill-defined horizon fools you to fly with one wing low (e.g. the "leans").
- Bad weather w/wo rain, snowfall or different kinds of lights give you a false impression of speed or AC attitude.
- NB: Oculogravic illusions are the most common subset of illusions in flight!

-gyral illusions

- Illusions during a ***change of G-forces*** with a false perception of AC turn.
- Illusions without visual cues are termed **somatogyral**
- Illusions with visual cues are termed **oculogyral**

3

Figure 8.1: SD Handout Side A.

SD Handout

Somatogyral example:

- Recovery from a coordinated turn, roll or a spin feels like entering a manoeuvre in the opposite direction.

Oculogyral example:

- AC movements affect the visual perception, giving rise to nystagmic eye movements which gives error in localization and motion of visual targets.

The illusions or input errors outlined above create SD which can be of either Type I or Type II, occasionally also developing into Type III.

Central errors create Type I SD and are the most dangerous type of SD since the pilot for different reasons doesn't use given reliable information of AC flight parameters. Examples:

- Coning of attention or "target fascination"
- Error of expectancy
- Mental stress
- Complacency
- Environmental factors like hypoxia, high-G or disease

Factors linked to SD

Flight environment

- VFR/IFR transition
- Isolated lights, bad visibility
- High altitude, low dynamic light flow input (peripheral vision)
- Featureless terrain (peripheral vision)

Flight manoeuvres

- Prolonged acceleration/deceleration (-gravic illusions)
- Recovery from prolonged turns (-gyral illusions)
- Subthreshold changes of AC flight parameters
- Ascent or descent pressure vertigo

AC factors

- Bad instruments (small HUDs, bad location in cockpit)
- Bad symbology
- View from cockpit (visual frame of reference, "break-off" risk)
- High manoeuvrability (angular and linear accelerations)

Aircrew factors

- Flight experience
- Training in instrument flights
- Currency of flying
- Physical health
- Alcohol and drugs
- Fatigue or task stress
- Cognitive factors like attention, operational qualification, anxiety

4

5

SPATIAL DISORIENTATION HANDOUT

Insert picture here

Aeromedical Institute ………
Address: ……………

For questions and recommendations:
Email: ………………

Figure 8.2: SD Handout Side B.

Chapter 9 – REFERENCES

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Human factors engineering		

14. Abstract

Recent accident statistics reveal that Spatial Disorientation (SD) is still a major threat to flight safety in many NATO countries. A review of SD training programmes as applied in most NATO countries, in agreement with STANAG 3114, shows that SD training is not fully developed. The goal of the report is to provide the necessary information to improve these SD training programmes. To this purpose, the report provides many detailed examples of ground-based and in-flight SD training scenarios. Ground-based training devices range from Barany chairs to Full Flight Simulators; in-flight SD training scenarios are described for rotary wing as well as for fixed wing aircraft. A separate chapter is devoted to SD avoidance training for Night Vision Devices.

The report also pays attention to the optimization of the SD training programme by selecting the appropriate SD scenarios, by choosing and training the right personnel and by the suitable integration of basic and continuation SD courses into the pilot training programme. An adequate training programme will enhance SD awareness, and consequently, flight safety.

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