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.