# 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 (< 0.5º/s²) 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 0.8m/s². 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).

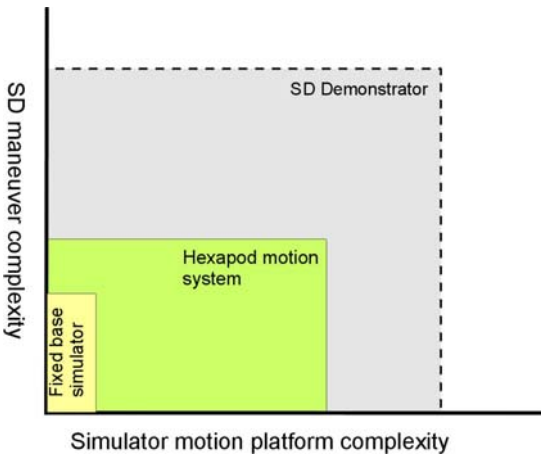


**Figure 3.1: Motion System Complexity Enables More Complex SD Manoeuvres to be Simulated.**

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.

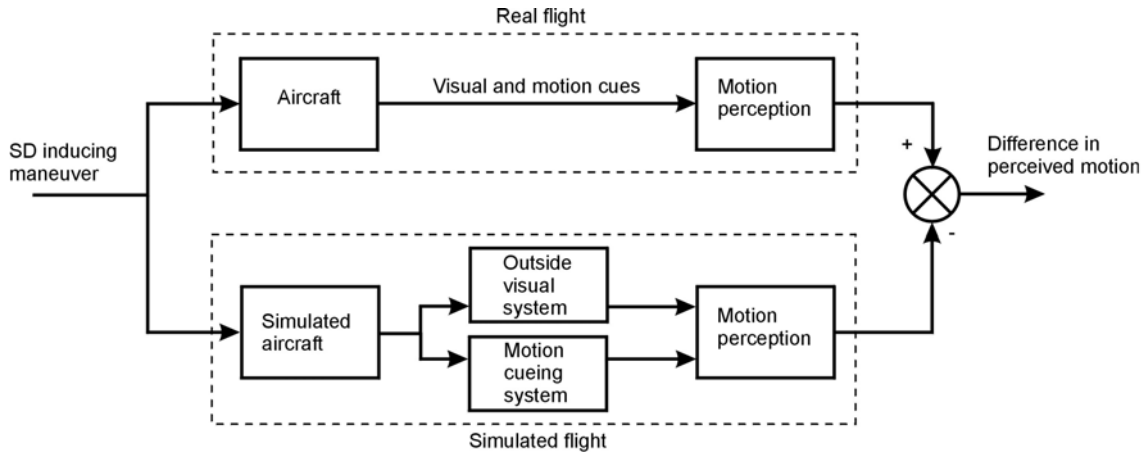


**Figure 3.2: Scheme for the Analysis of Perceived Motion in Real and Simulated Flight.**

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.

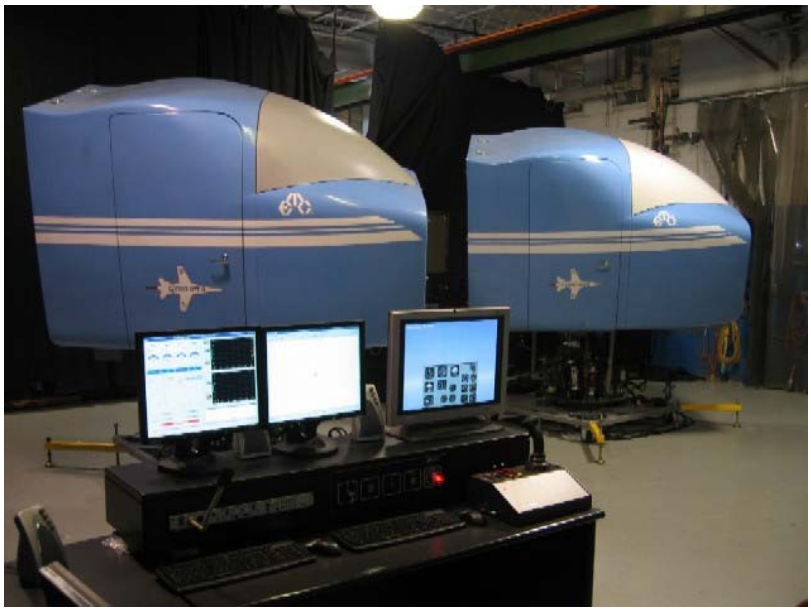

**Figure 3.3: Gyro IPT II (ETC, Southampton, PA).**

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

[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.

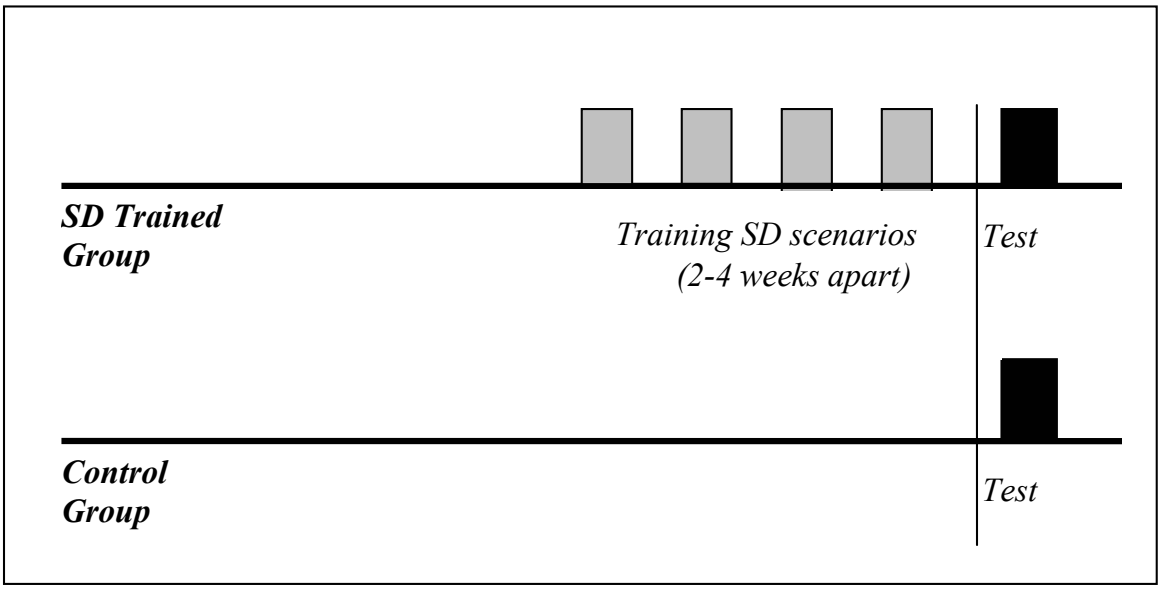


**Figure 3.5: Diagrammatic Representation of the Trial Design.**

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.

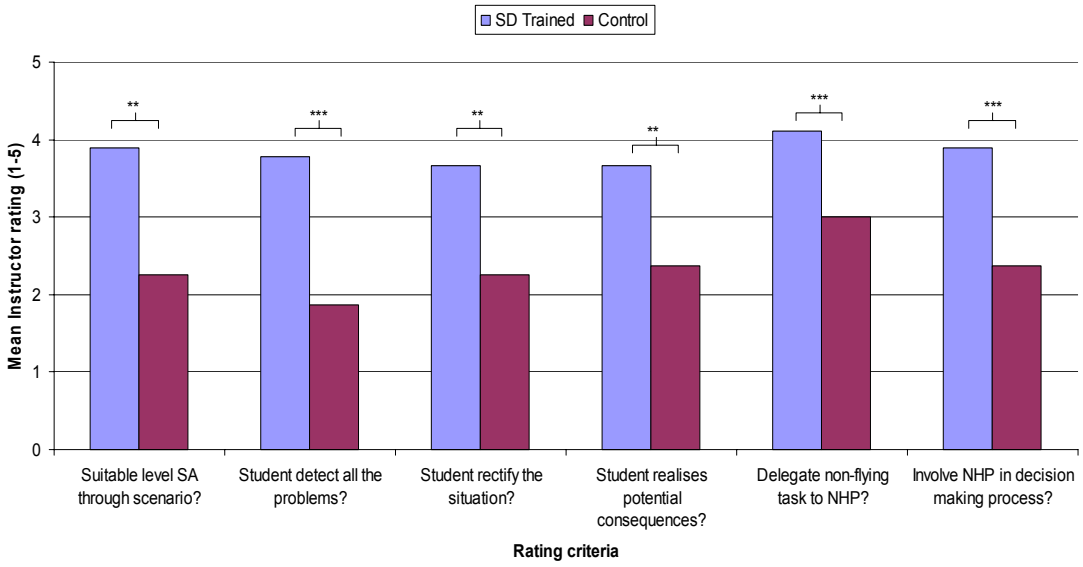


**Figure 3.6: Mean Instructor Ratings for the SD Trained and Control Groups in the Test Scenario (** p < 0.01, *** p < 0.001).**

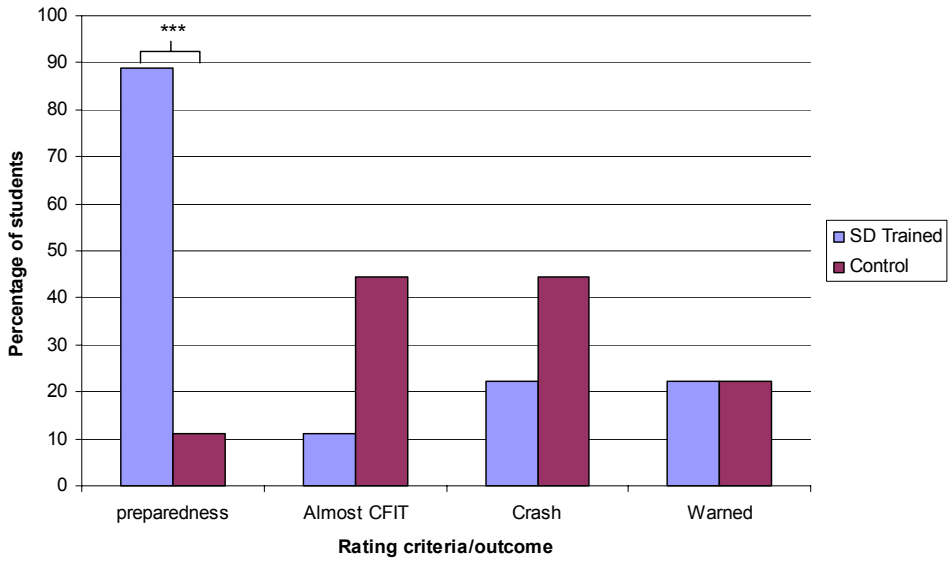


**Figure 3.7: The Percentage of Students in the SD Trained (n = 9) and Control Groups (n = 9) in the Test Scenario who were Rated by the Instructor as Well-Prepared for the Unexpected; also the Percentage of Students where the Outcome of the Scenario was almost CFIT, a Crash, or Warning from External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