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Technical Evaluation Report

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Introduction

Spatial disorientation is characterised by the failure of the operator to sense correctly the position, motion or attitude of the vehicle, or of him/herself, within a fixed co-ordinate system provided by the surface of the earth and the gravitational vertical. Spatial disorientation (SD) in flight, where the operator is the pilot and the vehicle is an aircraft, has been a problem since the early days of powered flight, and is a topic that has been discussed on numerous occasions within the NATO community. Yet, despite an increased understanding of the multifactorial aetiology of SD and improvements in the display of information to the aviator to facilitate the perception of veridical spatial orientation (SO), accidents primarily attributable to SD continue to occur. Indeed, as technologies of manufacturing, quality control and aircraft maintenance improve, the proportion of accidents (*syn.* mishaps) due to SD has increased. This would appear to be due, at least in part, to the introduction of new technologies, such as night vision goggles (NVGs), that have allowed flight operations in environmental conditions which previously were not possible.

In view of the apparent lack of progress in combating SD and the continuing accident rate with its loss of life, loss of aircraft and high financial cost, the Human Factors and Medicine Panel of the Research and Technology Agency considered it to be timely for the topic of SD to be revisited in the light of emerging and recently developed techniques and technologies which might have application not only to SD in flight but also in other military environments.

The 'Call for Papers' issued in June 2001 solicited unclassified contributions on the following topics: 1) Lessons learned from over 40 years of SD studies in the aeronautical environment (Mechanisms involved, Predisposition to SD, Role of cognitive factors). 2) How non-mishap SD may negatively impact crew performance and mission effectiveness (Air environments, Land environments, Sea environments). 3) Potential predisposition to SD using various head-out devices, NVG, HUD, HMD etc. (Day/night missions, Over water, Influence of visual conditions). 4) Effects of artificial visual environments (Virtual environment immersion, Enhanced and/or synthetic vision systems in vehicle manoeuvring and weapon delivery). 5) Spatial disorientation in new vehicular environments (Results of testing supermanoeuverable aircraft, uninhabited vehicles etc., Display and control issues). 6) Underwater disorientation (Helicopter ditching at sea, SEALS operations, Submarines). 7) Traditional and innovative SD countermeasures for tri-servcice warfighters (Training devices and protocols, Onboard equipment, Cognitive and sensorimotor aids, Visual and auditory symbology, Peripheral visual information, Tactile displays). 8) Standardisation of SD issues (Data Collection, Training methodologies, Equipment characteristics)

Forty-eight of the abstracts submitted were chosen for inclusion in the programme of the Symposium that was held in an appropriately sized and well equipped theatre of El Palacio de Congresos, La Coruña, Spain, on April 15-17, 2002. Thirty-four abstracts were selected for oral presentation and 14 for presentation as posters. The oral communications were grouped into six sessions; 1) Recent advances in causal mechanisms. 2) Operational and psychological consequences. 3) SD in land sea and virtual environments. 4) SD training programs. 5) SD countermeasures and training tools. 6) Cognitive and sensory aids to (preventing *Ed.*) SD. The Symposium ended with a free ranging 'Round Table' discussion with contributions from the platform and the audience. At the Symposium, two oral communications and one poster were withdrawn.

TECHNICAL EVALUATION

Incidence of Spatial Disorientation

In the Air.

The ubiquitous nature of SD in flight was revealed by three questionnaire surveys. Those carried out in the USAF (**7**) and the UK (**8**) employed similar questionnaires. Analysis of the responses of 2582 USAF and 752 (RAF, RN & Army) aviators were analysed and revealed generally comparable SD experiences, major differences being attributable to the small proportion of helicopter pilots in the USAF sample. Not surprisingly, 'the leans' was the most frequently reported type of SD (84%) followed by various visual illusions (76% - 40%). The causal factors: 'Distraction / Task saturation' (64%) and 'Poor crew co-ordination' (46%) featured highly in the ranking of responses; a finding that has important implications for SD training. 8% of the USAF aviators and 15% of the UK aircrew had experienced SD incidents of sufficient severity to adversely affect flight safety. In a SD questionnaire survey of 407 Hellenic Air Force pilots, 34% reported that they had never experienced an illusion in flight (**9**). Of those who had experienced SD, 'the leans' was the most frequently reported (47%). As in the USAF/UK surveys, 'Erroneous bank correction when using attitude indicator' or 'Flight instrument reversal' was not uncommon with incidences of 23%, 31% & 24% in the USAF, UK and HAF surveys respectively. A survey of 134 USArmy/National Guard aviators (**24**) found that 71% had experienced a SD incident in flight. The number reporting an SD experience was positively correlated with flight hours and ranged from 40% in those with less than 500 hrs to 100% of the pilots with 3500 – 4000 hrs in the air. In a study of 80 Spanish Air Force aviators (**12**), it was found that 73% of the fighter pilots had experienced SD but only 26% of transport pilots.

Incidence of SD accidents. Whereas SD experiences are generally common, accidents (*syn.* Class A mishaps) in which SD is implicated are relatively rare. No paper surveying accident statistics was presented at the Symposium but several authors quoted accident rates. For example, in the period 1992 – 2000, SD was a major or contributory factor in 20.2% of USAF Class A mishaps. US Army and US Navy rates over a similar period were 27% and 26% respectively (**7**). In the UK the proportion of SD related accidents over the past 30 yr. has ranged from 6% (Navy, 1972-1984), 12% (RAF, 1973-1991) and 21%(Army, 1971-1982) (8). In the Polish Air Force, some 8% of accidents were considered to be due to SD (**21**). USAF Class A mishaps rates over the period 1972-2000 show a progressive fall in the overall rate from 2.5 accidents per 100,000 flying hours in 1972 to a rate of 1.0 in the year 2000. In contrast, the SD accident rate has fallen from 0.5 to 0.25 over the same period and has been more or less constant for the last 15 yr. (**18**)

In Land Environments.

Three papers described SD in drivers of motor vehicles. Motorists Disorientation Syndrome (MDS) (**13**) is a condition in which the driver experiences an illusory veering or tilting of the car which can be so compelling as to cause inappropriate control. The condition is considered to be a functional disorder – nosologically a phobic postural vertigo – as it is not associated with any vestibular abnormality. The condition is not common and is amenable to treatment by cognitive behavioural therapy and desensitisation to motion stimuli.

The disorientation, dizziness, blurred vision and postural imbalance reported by race car drivers (**14**) is an even more esoteric condition than MDS as there are few who have driven on the modified Texas Motor Speedway. From an analysis of the trajectory of the car on the race track, the authors concluded that these symptoms were attributable to the cyclical acceleration, having peak intensities of 4.3 G_y and 3.0 G_z, which the drivers experienced twice each circuit of the track.

Drivers of an armoured vehicle experienced mild SD when using a binocular visual display that was driven by a head-slaved camera system mounted on the top of the vehicle (**46**), although more troublesome was the motion sickness induced when using the visual display. However, motion sickness scores were halved when the camera was (or cameras were) slaved to head position in pitch, yaw and roll than when there was no roll compensation. No significant differences were found between mono or stereo systems or with enhanced stereo. Paper 16 described an experiment involving the control of a small robotic vehicle carrying cameras to give a mono, stereo or enhanced stereo views to the remote operator. A task dependent benefit of the enhanced stereo was demonstrated.

Reference was made in paper **6** to a form of SD, characterised by errors in the spatial localisation of a visual target, as can occur whilst tracking on an anti-aircraft gun platform. In centrifuge experiments, in which a seated subject had to set a visual target to the perceived horizontal when exposed to an X axis acceleration, it was found that the depression of the horizon did not accord with the angular deviation of the resultant force vector. A significant depression of the horizontal occurred at a radial acceleration of only 0.014 m/s^2, where the deviation of the resultant force vector was only 0.08deg., but with a G_x of 1.5m/s^2, giving a resultant at 12deg, the horizon was depressed but 0.6deg. The reason for this apparent amplification of the oculogravic illusion at low radial accelerations and substantial suppression at higher intensities is covert.

In Water.

The SD and other difficulties experienced by those aboard on attempting to escape from a ditched helicopter are well recognised. However, paper **15** showed that the occupants trapped within a capsized rigid inflatable craft (RIC) can be in a worse predicament as they have to locate an escape hatch in the inverted hull. Several incidents in which the crew of capsized RICs failed to escape were described. These emphasised the need for better orientational cues to help those trapped within the dark of the inverted hull to find the escape hatch. A case was made for the crews of RICs to have escape training in a ‘dunking’ simulator, such as is currently practised by those who fly in helicopters.

Non vehicular.

Exercise induced intolerance is a recently described balance disorder in which symptoms of nausea, dysequilibrium and dizziness are precipitated by bouts of exercise involving head movement. Paper **41** presented the findings from a study of 15 military patients. All responded favourably to a tailored exercise programme with active and passive motion of head and body. After therapy, lasting on average 4.6 wk, they all returned to active duty, albeit with a recurrence of symptoms in four of the patients, three of whom were from the group of five smokers and one from the ten non-smokers.

Prophylaxis

General.

The three principal approaches to preventing SD, or at least reducing the frequency of SD incidents and accidents, were outlined in the Keynote Address, they are: 1) Selection and training, 2) improved displays for maintaining spatial orientation and for recovery from unusual attitudes (UAs), 3) Systems for the provision of pilot assistance, and autonomous systems for recovery from UAs and prevention of controlled flight into ground (CFIG). However, the speaker was not sanguine that SD accidents would ever be completely prevented either in military aviation or in the less well-regulated world of general aviation. Nevertheless, it is the objective of the USAF Research Laboratory’s SD Countermeasure Program to reduce the SD mishap rate by some 50% in the next 5 yr. and eventually eliminate SD as a significant factor in USAF mishaps (**18**).

Selection and Training.

No paper dealt with the topic of selection, but seven papers described the approach to SD training. These covered training in the USAF (**18**), US Army Air Force (**24**), and the Air Forces of France (**22**), Germany(**19**), The Netherlands (**20**), Poland (**21**), and the UK Army (**25**). All of the programmes had a common objective, namely: to help the aviator recognise SD, the flight conditions in which it was likely to occur, and to understand causal mechanisms. In all the countries, this objective was achieved by classroom lectures followed by some form of practical demonstration. Except in the UK Army, this SD demonstration is carried out on ground-based, motion devices which vary in complexity from a simple (Barany) rotating chair to a full-mission, dynamic simulator (**20, 21, 24**). Devices that are, in effect, short arm centrifuges, such as the ETC Gyrolab 2000 of the GAF (**19**) or an ‘eccentric mode 3D rotating chair’ (20), are used to demonstrate, *inter alia*, somatogravic and oculogravic illusions. The Générateur d’Illusions Sensorielles (Sensory illusion generator) employed in France (**22**) has a 3m arm with a cab having motion in pitch yaw and roll that can be controlled by the occupant. In Poland, a 9m arm centrifuge with a tilting gondola is deployed for SD training (**21**). The demonstration of visual illusions is no less important, perhaps even more important, than the demonstration of vestibular illusions, as visual problems are reported with high frequency in questionnaire surveys. Experience of visual illusions is provided by the use of the visual display of a SD trainer (**19**), a flight simulator (**20, 21, 22**) or a facility specifically designed for this purpose (**20,22**).

In some Air Forces a full-mission, flight simulator is used to give aircrew experience of scenarios in which SD can occur, or in which accidents have occurred, as well as to practise recovery techniques (**19, 21, 24**). USAARL has developed "SD awareness scenarios", based on actual accidents, for SD training in helicopter flight simulators (**24**). Despite favourable comment by those who have flown the demonstration sorties, they have not been incorporated in most of the USArmy/National Guard simulator training programs because their use was not obligatory.

Validation of the effectiveness of SD training is fraught with problems. It is reassuring to have favourable reports from those being trained, but more meaningful is reduction in the SD accident rate. Unfortunately, accident rates are a noisy statistic, especially when the criteria for deciding if SD is a relevant factor are not clear-cut and are amenable to individual interpretation (**25**). Internal validations, made by those receiving instruction, do provide feedback to course organisers, although they are far from being an absolute measure. Thus the in-flight SD demonstrations carried out in the UK Army Air Force were rated as "extremely effective"(**25**), while the flight simulator scenarios of the US Army Air Force were considered to be "a great training experience". "Excellent" to "good" ratings were given to the demonstration of the 'graveyard spin', both with and without hands-on recovery, in the GAF Gyrolab 2000 trainer (**19**); demonstration of 'a dark take-off', 'the leans' and 'sub-threshold rotation' were less favourably rated.

It is to be regretted that the important question: What motion cues are really required for effective SD training? was not addressed by any of the Symposium participants. However, paper **23** described the kinematic modelling of a motion platform, having a mechanism with differing configurations of revolute and prismatic joints. The model could be employed to optimise transient or continuous motion cues which would engender perceptions of spatial orientation, or disorientation, comparable to those evoked by specific aircraft manoeuvres in flight, while not producing, or at least minimising, any deleterious side effects. The model incorporates vestibular system dynamics, but no consideration is apparently given to visual-vestibular interactions or to the role of the idiotropic vector in the perception of spatial orientation that feature in the model described in paper **1**.

Changes in postural and cognitive function following exposure to the motion stimuli of a ground-based SD demonstrator. Postural activity was increased in comparison with pre-exposure control levels and was greater in older pilots (39-50 yr. old) than in a younger group (20-25 yr. old) (**35**). Another study (**12**) of postural activity was carried out on 80 pilots after SD training on a 'Gyro GPT II' rotator. 'Computerized Dynamic Posturography' (Neurocom Equitest) revealed that the 'Vestibular Response' was depressed, relative to normative values following the demonstration. This effect was greater in a group of fighter pilots than in a group of transport pilots, and was considered to be indicative of a greater dependence on visual information by the fighter pilots. In another study (**11**), degradation of cognitive function, as indicated by performance of 'Letter Cancellation' and 'Digit Symbol Substitution' tests, was found following SD training in 'Gyrolab'. The investigation had adequate pre- and post-exposure controls and both tests showed significant impairment. It is an open question whether the decrement in performance is a specific effect of the motion stimuli, or is just an expression of reduced motivation to perform the tasks after more interesting and involving experience in the SD demonstrator.

Presentation of Information on Spatial Orientation

Visual.

Only two papers specifically addressed the topic of the visual display of information for aircraft orientation. The contribution of a chequerboard pattern to the peripheral, visual field was assessed by the magnitude of postural sway that movement of the pattern could induce in the viewer (**28**). The finding that there was still an effective stimulus when the peripheral field was limited to 105deg or when a central area of 20deg x 20deg was omitted, is compatible with earlier work on the postural effects of dynamic ambient visual cues. The other paper described an experiment that compared a 'moving horizon'(MH), a 'moving plane'(MP) and an 'arc segmented'(ASR) attitude display in a PC based flight simulator program (**30**). For both perturbed flight and UA recovery, the best performance was achieved with the ASAR display, despite the preference by the flight cadet subjects for the MH (inside-out) display. While the link between psychophysical responses and display symbology is of importance, it should be remembered that there is along way to go from laboratory experiments to operational implementation.

Other papers dealt with aspects of behaviour and perception with different visual displays. Contrary to expectation, pilots who wore a helmet mounted display (HMD) having a conformal horizon, attitude display, did not exhibit a head tilting response, i.e.the optokinetic cervical reflex (OKCR) when flying in simulated VMC (**44**). It was found that in both the simulated IMC and VMC phases of the flight requiring bank angles of up to 80deg, there was negligible head tilt. The lack of an OKCR was attributed to the pilots using bank and pitch scale information in the display to maintain their orientation in both experimental conditions.

Paper **29** describes a series of experiments which demonstrated the influence of a head mounted display on the perception of the vertical. Subjects were required to set a luminous, linear target to the perceived earth vertical when either the head or the frame of reference, in which the target line was displayed, were tilted in roll through angles of up to ±40deg. The largest errors (≈ 6deg) occurred when the HMD displayed a virtual frame (30deg x 23deg) that moved with the subject's head. Smaller errors were made when the frame in which the target line was displayed was tilted; they were least when the target line was presented within a circular frame. In a further set of experiments in which the subject was tilted bodily through angles of ±30deg from the vertical, the greatest errors (of up to 10deg) were again made when the HMD displayed a virtual frame that moved with the head. Errors were less when the HMD virtual frame moved with the tilting chair, and were least when the frame was circular.

The perceived visual horizontal was also shown to be influenced by the optical structure and textural features of the display in a centrifuge experiment in which subjects, facing radially, were exposed to X axis accelerations of 1.0, 1.5 and 2.0 G_x (**37**). In the dark, the visual horizontal, as indicated by the location of a single, moveable LED, was depressed by some 12deg at $2G_x$. When the LED was viewed against an illuminated background frame that could be tilted in pitch through ±20deg, the oculogravic illusion was substantially suppressed, and the location of the perceived horizon was then principally determined by the pitch angle of the background frame.

Human centrifuge studies of the influence of lateral ($+G_y$) and longitudinal/lateral ($+G_z/+G_y$) acceleration were carried out in order to investigate possible SD problems during manoeuvring in an agile aircraft (**2**). Perceived earth vertical was indicated by positioning a cruciform target in a head-up display, and apparent geocentric body attitude by indication on a semicircular scale. At lateral accelerations of 0.5 to 3.5 G_y the visual vertical was deviated in roll, albeit through a smaller angle than the resultant vector made to earth vertical except at 3.0 and 3.5 G_y. With combinations of longitudinal and lateral accelerations, the perceived roll angle was substantially less than the deviation of the resultant vector. In a further series of experiments to study the interaction of visual with vestibular/proprioceptive systems, it was found that in four subjects the illusory perception of roll decreased when the eyes were closed, whereas another two subjects exhibited the opposite effect. This increase in the somatogravic roll illusion was accompanied by reports of SD, such as: "a sense of endless roll", "constant roll to the right, "impossibility to determine spatial attitude". These dynamic perceptions of movement, in some cases a true vertigo, would appear to have occurred in a steady state force environment without concomitant angular stimuli.

Another centrifuge study, related to the simulation of the force environment of an agile aircraft, assessed the subjective effects of high angular accelerations in pitch or roll whilst under $+G_z$ load (**36**). Experienced centrifuge subjects were little disturbed by angular movements, having peak accelerations of 1-10rad/sec^2 in pitch or roll, through angles (of 5–27deg) calculated to give G_x or G_y components of 0.5-1.5G with G_z of 1-8 G. Subjective discomfort, on a scale of 0-10, rarely rose above a score of 4 ("movement felt but not disruptive") in any of the 26 experimental conditions in both pitch and roll. The subjective rating increased with the magnitude of the X or Y axis acceleration, but there was no effect attributable to the rate of the movement. Unfortunately the authors gave no information on the kind of sensations induced by the procedures nor did they discuss the relative contribution of the cross-coupled stimulus to the semicircular canals and the stimulus to the otolith organs that occurs with the change in the orientation of the head to the linear acceleration and angular velocity vectors.

Tactile

The use of tactile stimuli to give information for spatial orientation or other components of situational awareness is a maturing technology. Paper **31** described the Operational Utility Evaluation recently conducted on the Tactile Situational Awareness System (TSAS) developed by the US Navy over the past 10yr. Evaluations carried out in CV22 helicopter simulator and in flight in a MH-53M have shown that errors in maintaining hover, in both actual and simulated flight, were less when TSAS was active, and that the system reduced subjective workload. TSAS was also shown to be effective in cueing TF climb/dive commands, tactical lateral steering guidance, flight director guidance for instrument approaches, and location of threats – the latter being received most enthusiastically by the aircrew.

Evidence that the interpretation and utilisation of tactile cues did not impose a burden on the performance of a closed loop task was provided by measures of performance of a hovering task both with or without NVGs in a helicopter simulator (**49**). In both conditions, the presence of a tactile torso display improved performance, there being little difference between a simple tactile display and a more complex one. More significantly, the presence of the tactile display largely overcame the decrement in performance wrought by an aural secondary task, without increase in ratings of mental effort made by the pilots. These experimental results give substance to the claim that a tactile display can provide 'intuitive' cues for spatial orientation, or in other words, cues that do not require high level processing within the central nervous system. The study also found little difference in the performance enhancement produced by simple and complex torso display. Indeed, the latter could be disadvantageous as it is less 'intuitive' and has claim on higher level processing resources.

TSAS has been shown to be of assistance to Special Tactics Forces for navigation in the air and on the ground (**32**). A simple configuration of tactors on a belt, coupled to a Global Positioning System (GPS) receiver, was used by personnel engaged in 'High Altitude High Opening' operations to indicate cross-track and glide slope error during descent. For ground navigation, only three tactors were used to indicate deviation from a predetermined course or proximity to a designated waypoint. Operator performance was better and deviations from track were lower when TSAS was active than when only the visual display of the GPS was used.

Tactile navigation cues have also been successfully trialled in the marine environment (**33**). One system uses the concept of a virtual corridor with tactor activation when the surface vessel or diver deviates from track as far as a 'wall' of the virtual corridor. In another application, the deviation of a craft's heading (in any of the four quadrants) from that required to reach a target waypoint was indicated by the location and frequency of tactor activation.

Cognitive assistance.

Paper **27** described components of a system that would monitor the pilot's functional state and flight parameters in order to detect any degradation of performance that would indicate excessive workload or diminution of cognitive function. On recognition of a problem, the system would provide assistance to the pilot or, if necessary, take over full control of the aircraft until the pilot was able to resume control. It is envisaged that the system will have three modules: 1) To monitor the status of the aircraft situation and outside environment, and to recommend actions. 2) To monitor the pilot's physiology and behaviour to provide an estimate of pilot state. 3) To monitor the mission plan and manage the interface to the pilot. The integrated output of these modules will provide cognitive assistance through adaptive automation and decision support. It will have the potential to cancel SD by effective real-time adaptive counter measures using flexible levels of autonomy governed by pilot-agreed plans. The authors were of the opinion that the implementation of such a system is technically feasible, but it is inchoate in so far it has yet to be implemented in hardware.

SD Causal Mechanisms

General

The role of the vestibular and visual sensory systems in the aetiology of SD are reasonably well understood and can be effectively modelled (**1**). Such models can also be employed in the analysis of SD accidents and for the reproduction of flight scenarios, that include the possible perceptions of the pilot, to aid investigators (**10**). However, the interaction of vestibular and cardiovascular responses in causing, or more likely potentiating, SD has not been explored in depth. The insentient pilot, because of G-induced loss of consciousness (GLOC) is, by definition, disorientated. The syndrome 'Almost loss of consciousness' (ALOC) is also induced by +Gz load and can impair cognitive function with the consequent degradation in perception and interpretation of spatial information. The experimental induction of ALOC by pulses of Z-axis acceleration (**48**) revealed the range of physical and emotional symptoms as well as cognitive deficits that could occur. These behavioural changes were associated with a fall in the level of cerebral tissue oxygenation, although they often persisted well into the post-exposure period when cerebral oxygenation had recovered.

Spatial disorientation on G-transition and on recovery from high rates of roll was discussed in paper **4**. Several factors were considered to be implicated: 1) The effect of intense vestibular stimulation causing a decrease in cerebral blood pressure with the consequent reduction in G-tolerance and increased likelihood of ALOC or GLOC. 2) Interference with vision by inappropriate vestibular nystagmus on recovery from the roll and loss of external visual references during the manoeuvre. 3) Illusory sensations of rotation on recovery.

Individuals who are motion sick not infrequently complain of dizziness that can be of sufficient intensity to constitute SD. The associated loss of well being and changes in behavioural state with impairment of cognitive function can, it was argued (**38, 43**), increase susceptibility to SD. Motion stimuli can induce drowsiness, the ‘Sopite Syndrome’, without frank motion sickness, and this may contribute to SD because of the attendant low level of behavioural arousal and diminished cue utilisation.

Conclusions and Recommendations

The Symposium provided a valued update about the prevalence of SD incidents and accidents within the Air Forces of several countries, and on the training aircrew receive to combat the problem. Existing collaborative work on these topics could profitably be extended to involve other countries. Standardisation of the collection of data on accidents and the criteria to be employed in the identification of SD as a primary or contributory cause of the accident would be advantageous.

In SD training, the demonstration of vestibular illusions should not overshadow the demonstration of visual illusions or instruction on the role of distraction and lack of crew co-ordination in the causing SD. There is also benefit in the demonstration of SD scenarios in a full-mission, flight simulator, preferably one having a good visual display and motion base.

Centrifuge experiments, which simulate aspects of the dynamic environment in manoeuvring agile aircraft, have found large individual differences in the SD induced. Further studies are needed to determine the variability of subjective responses to combined G_z/G_y and G_z/G_x in the relevant aircrew population. The benefit of centrifuge training to desensitise those aviators, who have strong illusions, merits assessment.

Tactile displays have been shown to provide intuitively useable cues for spatial orientation, navigation and other tasks in aerial, marine and terrestrial environments. There is evidence that tactile cues provided by relatively simple displays are processed within the central nervous system without making demands on higher level resources. Current work on the development of more complex tactile stimulators (*e.g.* one providing a sensation of movement) or of displays with a more complex coding (e.g. by increase in the number of tactors, or their vibration frequencies) should take care that the increase in information provide by a more complex display is not at the cost of placing an increased load on higher level processing and thereby vitiating one of the principal benefits of a tactile display.

Work on the feasibility of developing a system for the provision of cognitive assistance to the pilot, or even taking over control, should be continued. The system, as envisaged, has the potential to combat SD and prevent SD accidents, but there are considerable technological hurdles to be overcome, not least the development of a module to monitor reliably the pilot’s physiology and behaviour in a non-invasive manner.

Modelling of sensory systems that subserve the perception of spatial orientation is of value in understanding causal mechanisms of SD and for the prediction of the sensations and control responses of a pilot in a SD accident. It is also useful in the design of control systems of simulator, motion platforms. More information is needed on inter-subject variability of responses to motion stimuli, in order to be able to substantiate statements about the likelihood of occurrence of a predicted response in an accident scenario.

Rigid inflatable craft should have better provision of cues, within an inverted hull, for the spatial location of the escape hatch. Crews should also have training in escape from an inverted craft, similar in principle to that given to helicopter aircrew.

Service medical officers should be made aware of the SD and other symptoms of the Motorists’ Disorientation Syndrome and of the Exercise Induced Intolerance Syndrome, as these conditions should be considered, amongst many others, in the differential diagnosis of vertigo and SD.