Chapter 2 – PHYSIOLOGICAL AND PERCEPTUAL LIMITATIONS: CURRENT APPROACH IN BROWNOUT

2.1 INTRODUCTION

This chapter describes the mechanism of orientation in flight and the inadequacies of the human sensory system in dealing with the brownout phenomenon. It also outlines basic flight requirements that are essential to land the helicopter under Degraded Visual Environment (DVE) conditions.

2.2 BACKGROUND ON SPATIAL ORIENTATION IN FLIGHT

Our perception of position, motion and attitude with respect to the fixed frame of reference provided by the gravitational vertical and the surface of the earth is based on the neural integration of concordant and redundant information from the visual, vestibular and somatosensory (tactile cues and proprioceptors) systems [2]. To a lesser extent, the auditory system also provides information on orientation. Within this multi-loop control system, the individual components are mutually interactive and partially redundant because their functional ranges overlap. To the extent that their functional ranges do not overlap, the individual components compensate for each other's deficiencies. For example, if visual function is normal and external visual cues are unambiguous, at frequencies below 1 – 2 Hz, vision provides reliable sensory information from which orientation may be perceived correctly. However, when devoid of vision as in brownout and under instrument flight conditions, where the pilot has meager, if any, visual information outside of the instrument display, and at higher frequencies, vestibular information plays a significant role.

Our perception of correct orientation based on these sensory systems is developed under a normal 1G environment. Therefore, the relative contribution of the various sensory systems is significantly altered when exposed to unusual gravitoinertial environments such as in the air. Once we are airborne and subjected to abnormal or unusual accelerative forces, the information provided by different sensory modalities, particularly the vestibular apparatus and proprioceptors, may be interpreted incorrectly with potentially dangerous consequences. For example, the effective muscular response is redirected to maintain control of the aircraft rather than the maintenance of posture and equilibrium. In addition, the vestibular system is inadequate to perceive heave motion when devoid of visual input. Under continuous variation in both the magnitude and direction of the apparent gravitational field and prolonged rotational movements, the Central Nervous System (CNS) has the added responsibility of determining what sensory information is valid and what is not. When presented with reduced and or conflicting sensory information, it is normal to experience episodes of Spatial Disorientation (SD). Spatial disorientation is defined as the failure to perceive or perceive incorrectly the position, motion and attitude of the aircraft with respect to a fixed frame of reference, which is the surface of the earth and the gravitational vertical [2];[11]. The added responsibility to the CNS presents a major challenge when developing technological solutions to combat SD.

2.3 THE "BROWNOUT" PHENOMENON

Brownout/whiteout represents SD traps both because of its potential for obscuring the horizon, and overall visibility. As described briefly in Chapter 1 (Introduction), brownout/whiteout is a situation in which blowing dust or desert sand or snow from rotor down wash obscure both horizon and terrain features, and can lead to undetected drift or bank or even create vection (visually induced sensation of self motion). Specifically, when

descending vertically through the last 75 feet, the recirculation of dust or sand cause sudden loss of overall visibility. During formation flight, fine sand/dust coming from wingman also contributes to DVE. Moreover, fine sand does not remain stable over time but rather shifts in location and height as a result of wind direction.

2.4 PERTINENT ORIENTATION INFORMATION FOR HELICOPTER TAKE-OFFS AND LANDINGS

For safe helicopter landings the main source of information available to the pilots is visual contact with the environment. Focal vision uses the central 30 degrees or so of the visual field; it is concerned with object recognition and identification. It involves relatively fine detail (high spatial frequencies). The information processed by focal vision is well represented in our consciousness. Therefore, it contributes to the conscious percepts of orientation. During flights in Visual Meteorological Conditions (VMC), central vision allows distant judgment, depth perception employing binocular cues of stereopsis, vergence, motion parallax and accommodation. On the other hand, ambient vision involves broader areas of the visual field (including the visual periphery). It subserves spatial localization and orientation and is primarily involves with the position, motion and attitude of the individual/airframe in the environment. Under Good Visual Environment (GVE), ambient vision provides motion cues and position cues such as the horizon. In summary, focal vision orients the perceived object relative to the individual, whereas ambient vision orients the individual relative to the perceived environment.

2.5 PHYSIOLOGICAL LIMITATIONS DURING BROWNOUT

The potential SD traps from brownout can be compounded with the inherent vestibular inadequacies. The vestibular system is divided into the semi-circular canals responsible for angular acceleration detection and the otolith organs responsible for linear acceleration detection including head tilt. However, the vestibular system is a poor sense for spatial orientation in aviation (Figure 2-1). It concerns with the detection of signals arising from movements of the head and therefore does not necessarily inform the pilot about the state of the external world. Furthermore, as an integrated accelerometer, it is only sensitive to velocity changes (acceleration) and is unable to detect constant velocities. Moreover, changes in velocity below our perceptual threshold are not perceived. Therefore it is incapable of detecting sub-threshold drifts. It has also been shown that acceleration along the z (spinal) axis, i.e., heave motion, leads to uncertain and usually erroneous perception of velocity and direction of motion [8].

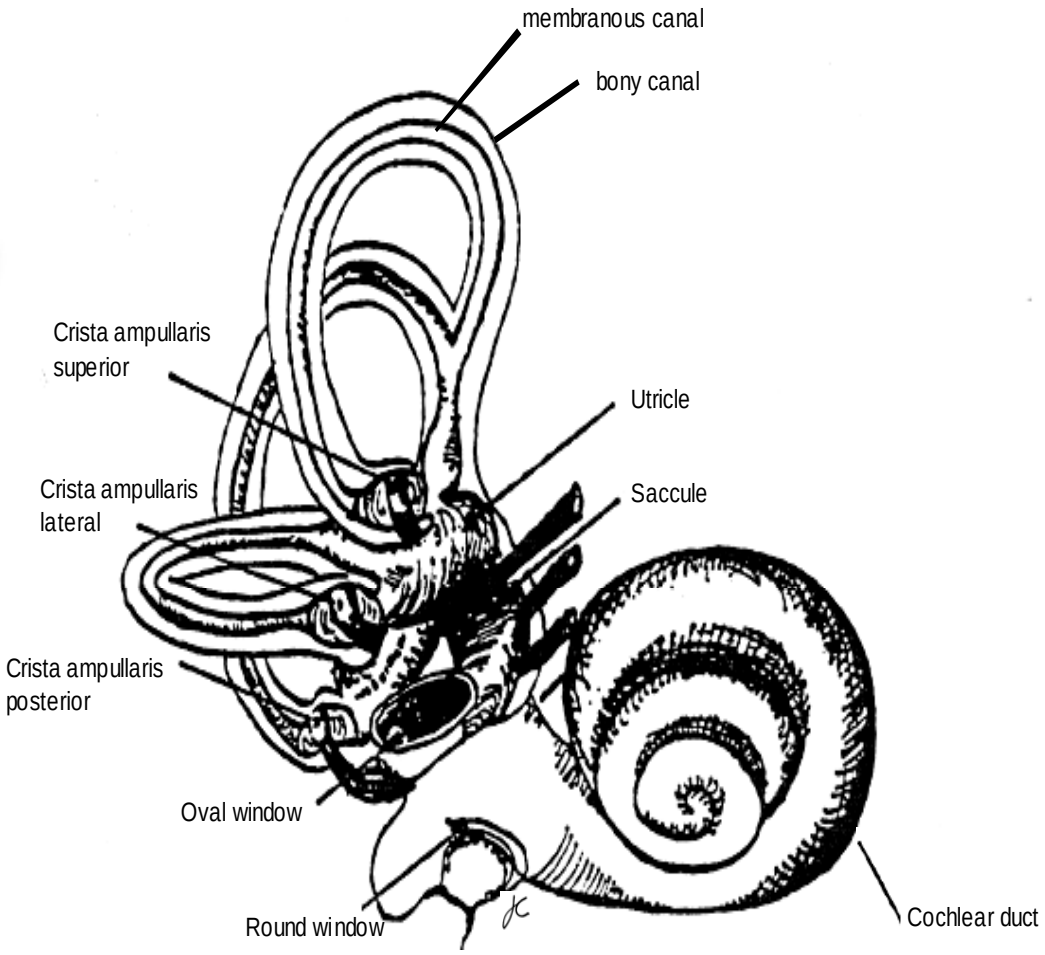

Figure 2-1: The Vestibular System. An illustration showing the relationship of the canals with the utricle and saccule.

Three common misperceptions during brownout could occur that may lead to dire consequences:

a) Sub-threshold lateral drifts often occur just prior to touchdown. The phenomenon appears when a gradual turn occurs at a rate that is below the threshold for detection of a change in angular velocity. The angular acceleration occurs smoothly enough for the semi-circular canals not to be stimulated. Perceptual threshold values are 0.14°/s² for rotation about the z-axis and 0.5°/s² for rotation about the x- and y-axis [2]. Detection thresholds also depend on the duration of the stimulation. The product of acceleration and stimulus duration is a constant for stimulus duration of 5 s or less. Thus, perceptual threshold in terms of angular velocity is 2.5°/s (Mulder's constant). Such brownout-induced disorientation can be referred to as Type I (unrecognized) SD in flight [10] as the pilot is unaware of the lateral drift.

b) The movement of dust or blowing dust during landing may give the pilot the impression that the helicopter is respectively banking or turning or vection (visually induced sensation of self motion) when it is actually in a level hover. Vection, can be induced by the nearly uniform motion of a large part of the visual field [3]. Vection occurs in the opposite direction to the stimulus direction, i.e., if the

dust and sand is circulated in a clockwise direction, it could induce a sensation of self motion in the counter-clockwise direction. Vection can occur across all six degrees of freedom of body motion for example, roll, pitch, yaw (circular vection) and linear translations along the x. y and z axes (linear vection) or some combination.

c) Without clear external visual references, deceleration from forward flight may give the false impression that the helicopter is pitching down, the somatogravic illusion. The otolith organ as in any physical accelerometer, follows "Einstein Equivalence Principle", and cannot distinguish between gravity and the inertial reaction force to any linear acceleration, so they actually indicate the orientation of the head relative to the gravitoinertial force. Without additional sensory information, the CNS cannot distinguish linear motion from gravity. However, neural processing seems to apply some kind of low-pass filtering to determine gravity from the resultant gravitoinertial acceleration signaled by the otolith organs. This is adequate for the detection of short duration self-induced head movements. However, sustained accelerations occurring in flight may be misinterpreted as pitch motion.

2.6 OTHER AGGRAVATING FACTORS THAT MAY PREDISPOSE SD

Typical aggravating factors (although not exclusive) that may lead to SD during brownout include fatigue, high workload, unexpected flight plan (or mission) changes, and inexperience. A specific aggravating factor for brownout is take-off or landing using Night Vision Goggles (NVG). Flying under NVG is a difficult task *per se* due to the reduction of visual Field Of View (FOV), reduced contrast, stereopsis, accommodation, differences in illumination perspective of objects due to light and shadows, differences in aerial perspective etc. However, hovering could abolish motion parallax. During night take-off and landings, aircraft lighting, can enhance the visual illusions by illuminating the brownout cloud. Rotor blades/dust interaction also may result in strong scintillation effects, which saturate parts of the NVG image and reduces the sensitivity (gain) of the system.

2.7 INADEQUACIES OF CURRENT LANDING APPROACH DURING BROWNOUT

A common landing technique is to choose noticeable features on the ground (rocks, bushes, trees, fences, etc.) in order to set up the approach and land at the designated Landing Zone (LZ). An example of the visual reference necessary to control the aircraft near the ground is shown in the following figure.

Figure 2-2: Helicopter Entering a Brownout Condition.

These external ground-based features provide the pilot with necessary and valuable information for landing. However, the sudden loss of visibility or degraded visibility abolishes visual guidance references (pre-identified landmarks as stated above), other moving targets, distance and height perception that are essential to control the aircraft near the ground.

As brownout is a sudden phenomenon that occurs close to the ground, there is little tolerance for error and inherent correction delay. Although the sudden loss of visual references would necessitate the transitions from VMC (Visual Meteorological Conditions) to IMC (Instrument Meteorological Conditions), there remains an inadequacy between task requirements (landing in a non-visual environment) and the lack of feedback for drift and height above terrain, especially in legacy aircraft equipped with only standard flight instrumentation. By the time when lateral drift is detected, corrective actions might not be implemented on time.

Whiteout landings pose a similar problem to the helicopter pilot. As the aircraft descends closer to the ground, rotor downwash stirs loose snow which is drawn into the rotors and circulated (figure below). Visibility is significantly reduced and plots must adopt landing strategies similar to those used in brownout landings. Whiteout mishaps have been reported by Scandinavian and Canadian members of the Task Group.

Figure 2-3: Helicopter Entering a Snow-Induced Whiteout Condition.

Figure 2-4: An Example of a Take-Off in Brownout Conditions.

During flights under Instrument Flight Rules (IFR) in Instrument Meteorological Conditions (IMC), pilots should be able to read the instrument displays that provide the necessary, yet basic, spatial awareness information with confidence. Pilots who are trained to trust their instruments will most likely ignore the physiological inputs during landing even if external visual cues are available in order to concentrate on the flight instruments. Therefore, the instrument displays should be functioning properly in order to provide veridical flight parameters. However, in GVE, peripheral (ambient) vision facilitates the detection of drift and height above terrain which are the most critical information required during take-offs and landings.

The helicopter, by nature is an unstable platform. Pilots have to "work" persistently with their controls in order to gain and maintain stability. Without inputs to the controls through either the Automated Flight Control System (AFCS) or hands-on control, the position of the helicopter in three dimensional space can only be maintained for a very short period of time. Usually, it is much shorter than the time that it takes to land the helicopter. This time period depends on the specific airframe and the environmental conditions.

The landing procedure itself is challenging. In order to descend and land from hovering, the helicopter pilot must reduce the torque (force). The reduction of force immediately (within a fraction of a second) requires a change of tail rotor power. The amount of tail rotor power change is determined by the amount of main power reduction (the torque) and is in turn determined through visual information obtained by the pilot. The impact of a change in tail rotor power is to create drift, which is compensated by moving the cyclic, in order to influence the requirement of power. This process requires "working" of the controls by the pilot in order to maintain stability. Moreover, as the helicopter is closer to the ground, the rotors are further influenced by the turbulence of air impacting the ground and the subsequent reflection off the ground surface. If mission requirement dictates that the landing procedure were to be sped up (i.e., a quick reduction in power), it would create a greater disturbance.

The fidelity of current helicopter instrumentation is not sufficient to execute instrument landing in remote and unfamiliar Landing Zones (LZ) in DVE. Therefore "brownout landing" in current helicopters relies on hands-on control and may be supported by AFCS in some legacy airframes. The requirement of external (or virtual) visual cues is an important factor for safe take-offs and landings. Therefore, additional technological aids are required to support the aircrew in situations of limited visibility due to rising and re-circulating loose particulates (sand/snow) in order to avoid the SD trap of brownout/whiteout.

In order to secure safe landing, mission related visual cues that will provide drift, Height Above Terrain (HAT), descent rate, ground speed, attitude, slope, terrain features, LZ location, obstacle clearance and moving obstacle detection must be available. Specifically, drift is the most crucial information prior to touchdown as mentioned above. Ground speed refers to the horizontal speed in the final phase of the approach. The attitude of the aircraft refers to roll, pitch and yaw information. The priority and importance of this information depends on the helicopter type. For example, there is a distinct difference between the CH-53 and CH-47. In the CH-53 the information of the pitch attitude of the airframe prior to touchdown is critical in order to prevent the tail rotor from hitting the ground. If a CH-53 encounters a nose-up attitude greater than 12° short of the ground, it will impact the ground with the tail rotor first. On the other hand, this critical issue is not of concern in the CH-47 because of its tandem rotor system.

Mission related technologies such as auto hover functionality, sensors, helmet-mounted displays (AH-64 vs. CH-53 vs. UH-1D, etc.) and knowledge of the known and unknown geographical environment and time of day are equally important in order to maintain the full capability to safely land the helicopter in DVE. In searching for technological solutions, the following human factors related issues must be taken into consideration:

a) Cultural mindset – Does the organisation support IFR training?

b) Self-confidence – the pilots' experience on the specific A/C, their specific role with respect to the mission will all exert an influence on the pilots' self confidence, regardless of their personalities.

c) Lack of ambiguity – the procedure and rationale that one should follow when two independent instruments showing contradicting data. Should this be allowed in principle? Should a solution be forced through the use of a third instrument in such cases?

d) Duplication of information displays – Since there are two crew-members on most platforms, identical information should be presented to both pilots, in order to allow the non-handling pilot to be able to alert the aircraft commander of safety concerns.

e) Workload – should be similar to those require for regular landing procedure. If a brief observation out the window in regular landing (e.g., NVG landing) is all that is required to provide enough data regarding attitude, drift, HAT, etc., then the brownout solution should aspire to maintain similar workload.

f) Latency – should be defined in numerical terms. For example, in AH-64 the latency between the movement of the head and the response of the Panoramic Night Vision System (PNVS) is around 50 – 100 ms.

g) Prevent coning of attention – A solution should be developed so that it will resemble known procedures such as those employed in NVG landing.

h) Perceptual issues – The implementation of such technology should be intuitive, easy to use and comprehend, and should be implemented in a manner that it would become intuitive (natural thing to do), not only in DVE, but also in normal procedures.

2.8 CONCLUSION

Brownout causes a loss of visual reference close to the ground, allowing little tolerance for error and a correction delay below that required for situational awareness. This will be compounded with inherent vestibular inadequacies. Sudden loss of visual references induces major changes in the piloting process, which increases the opportunity for SD. The discrepancy between task requirements (landing in a remote location in DVE) and insufficient information from legacy instruments and technology further compound the problem.

The potential risk mitigating strategies for rotary-wing brownout take-offs and landings could fall into two broad categories:

1) Technology development to overcome the environmental limitation described above under DVE conditions, for example, "see through" or "dust-penetrating" technology.

2) Technology development to overcome the physiological limitation under DVE conditions, for example, provide pertinent information, in an intuitive manner (better landing symbology systems or other sensory displays) to the pilot in order to compensate for the lack of external visual cues.

2.9 REFERENCES

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