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Subject: PILOT'S SPATIAL DISORIENTATION.

1. PURPOSE:

To acquaint pilots with the **hazards of disorientation** that is caused by **loss of visual reference with the surface.**

2. INTRODUCTION:

a. **Spatial Orientation** defines the natural ability to maintain our body orientation and/or posture in relation to the surrounding environment (physical space) at rest and during motion.

b. Genetically speaking, humans are designed to maintain spatial orientation on the ground. The **three-dimensional environment of flight** is unfamiliar to the human body, creating **sensory conflicts and illusions** that make spatial orientation difficult to achieve.

c. Spatial orientation in flight is difficult to achieve because numerous sensory stimuli (visual, vestibular, and proprioceptive) vary in magnitude, direction, and frequency. Any differences or discrepancies between visual, vestibular, and proprioceptive sensory inputs result in a sensory mismatch that can produce illusions and lead to **spatial disorientation**. Simply put, Spatial disorientation to a pilot means simply the inability to tell which way is “up”.

d. Good spatial orientation relies on the effective perception, integration and interpretation of visual, vestibular (organs of equilibrium located in the inner ear) and proprioceptive (receptors located in the skin, muscles, tendons, and joints) sensory information.

e. The attitude of an aircraft is generally determined by reference to the natural horizon or other visual references with the surface. If neither horizon nor surface references exist, the attitude of an aircraft must be determined by artificial means from the flight instruments. Sight, supported by other senses, allows the pilot to maintain orientation.

f. However, during periods of low visibility, the supporting senses sometimes conflict with what is seen. When this happens, a pilot is particularly vulnerable to disorientation. The degree of disorientation may vary considerably with individual pilots and their cumulative fatigue levels.

g. During a recent 5-year period, there were almost 500 spatial disorientation accidents in the United States. Tragically, such accidents resulted in fatalities over 90 percent of the time. Tests conducted with qualified instrument pilots indicate that it can take as much as 35 seconds to establish full control by instruments after the loss of visual reference with the surface. When another large group of pilots were asked to identify what types of spatial disorientation incidents they had personally experienced, the five most common illusions reported were:

i. 60 percent had a sensation that one wing was low although wings were level;

ii. 45 percent had, on levelling after banking, tended to bank in opposite direction;

iii. 39 percent had felt as if straight and level when in a turn;

iv. 34 percent had become confused in attempting to mix "Contact” and instrument cues; and

v. 29 percent had, after recovery from steep climbing turn, felt to be turning in opposite direction,

3. ANALYSIS:

Surface references and the natural horizon may at times become obscured, although visibility may be above visual flight rule minimums. Lack of natural horizon or surface reference is common on overwater flights, at night, and especially at night in extremely sparsely populated areas, or in low visibility conditions.

A sloping cloud formation, an obscured horizon, a “White-out” condition caused by fog, haze, or falling snow blending with the snow-covered earth surface, a dark scene spread with ground lights and stars, and certain geometric patterns of ground lights can provide inaccurate visual information for aligning the aircraft correctly with the actual horizon.

Other factors which contribute to disorientation are reflections from outside lights, sunlight shining through clouds and reflected light from the anti-collision rotating beacon. All these factors may obscure outside references leading to a disoriented pilot who may place the aircraft in a dangerous attitude as a consequence of sensory illusions.

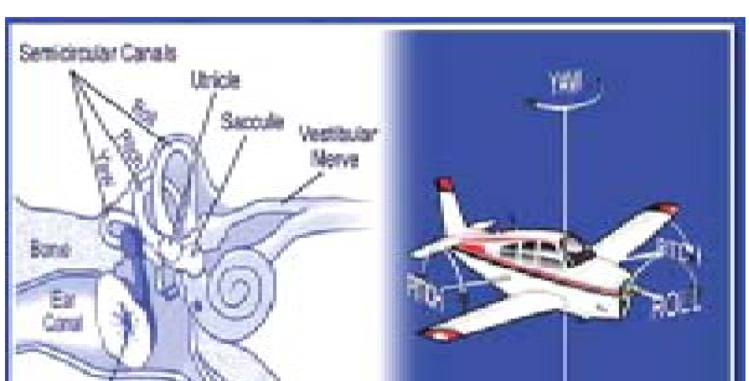
4. VESTIBULAR ASPECTS OF SPATIAL ORIENTATION:

The inner ear contains the vestibular system, which is also known as the organ of equilibrium. About the size of an pencil eraser, the vestibular system contains two distinct structures: **the semicircular canals**, which **detect changes in angular acceleration**, and the **otolith organs** (the utricule and the saccule), which **detect changes in linear acceleration and gravity**.

Both the semicircular canals and the otolith organs provide information to the brain regarding our body’s position and movement. A connection between the vestibular system and the eyes helps to maintain balance and keep the eyes focused on an object while the head is moving or while the body is rotating.

4.1 THE SEMICIRCULAR CANALS

The semicircular canals are three half-circular, interconnected tubes located inside each ear that are the equivalent of three gyroscopes located in three planes perpendicular (at right angles) to each other. Each plane corresponds to the rolling, pitching, or yawing motions of an aircraft.



Each canal is filled with a fluid called endolymph and contains a motion sensor with little hairs whose ends are embedded in a gelatinous structure called the cupula. The cupula and the hairs move as the fluid moves inside the canal in response to an angular acceleration. The movement of the hairs is similar to the movement of seaweed caused by ocean currents or that of wheat fields moved by wind gusts. When the head is still and the airplane is straight and level, the fluid in the canals does not move and the hairs stand straight up, indicating to the brain that there is no rotational acceleration (a turn).

If you turn either your aircraft or your head, the canal moves with your head, but the fluid inside does not move because of its inertia. As the canal moves, the hairs inside also move with it and are bent in the opposite direction of the acceleration by the stationary fluid.

a. This hair movement sends a signal to the brain to indicate that the head has turned. The problem starts when you continue turning your aircraft at a constant rate (as in a coordinated turn) for more than 20 seconds. In this kind of turn, the fluid inside the canal starts moving initially, and then friction causes it to catch up with the walls of the rotating canal.

b. When this happens, the hairs inside the canal will return to their straight up position, sending an erroneous signal to the brain that the turn has stopped–when, in fact, the turn continues. If you then start rolling out of the turn to go back to level flight, the fluid inside the canal will continue to move (because of its inertia), and the hairs will now move in the opposite direction .

c.Sending an erroneous signal to the brain indicating that you are turning in the opposite direction, when in fact, you are actually slowing down from the original turn.

4.1.1 VESTIBULAR ILLUSIONS (SOMATOGYRAL - Semicircular Canals)

Illusions involving the semicircular canals of the vestibular system occur primarily under conditions of **unreliable or unavailable external visual references** and result in **false sensations of rotation**. These include the Leans, the Graveyard Spin and Spiral, and the Coriolis Illusion.

a. **<u>The Leans</u>** is the most common illusion during flight and is caused by a sudden return to level flight following a gradual and prolonged turn that went unnoticed by the pilot. The reason a pilot can be unaware of such a gradual turn is that human exposure to a rotational acceleration of 2 degrees per second or lower is below the detection threshold of the semicircular canals. Leveling the wings after such a turn may **cause an illusion that the aircraft is banking in the opposite direction.** In response to such an illusion, a pilot may **lean in the direction of the original turn** in a corrective attempt to regain the perception of a correct vertical posture.

b. **<u>The Graveyard Spin</u> is** an illusion that can occur to a pilot who intentionally or unintentionally enters a spin. For example, a pilot who enters a spin to the left will initially have a sensation of spinning in the same direction. However, if the left spin continues the pilot will have the sensation that the spin is progressively decreasing. At this point, if the pilot applies right rudder to stop the left spin, the pilot will suddenly sense a spin in the opposite direction (to the right). If the pilot believes that the airplane is spinning to the right, the response will be to apply left rudder to counteract the sensation of a right spin. However, by applying left rudder the pilot will unknowingly re-enter the original left spin. If the pilot cross checks the turn indicator, he/ she would see the turn needle indicating a left turn while he/she senses a right turn. This creates **a sensory conflict between what the pilot sees on the instruments and what the pilot feels.** If the pilot believes the body sensations instead of trusting the instruments, the left spin will continue. If enough altitude is lost before this illusion is recognized and corrective action is taken, **impact with terrain is inevitable.**

c. **<u>The Graveyard Spiral</u>** is more common than the Graveyard Spin, and it is associated with a return to level flight following an intentional or unintentional prolonged bank turn. For example, a pilot who enters a banking turn to the left will initially have a sensation of a turn in the same direction. If the left turn continues (~20 seconds or more), the pilot will experience the sensation that the airplane is no longer turning to the left.

At this point, if the pilot attempts to level the wings this action will produce a sensation that t**he airplane is turning and banking in the opposite direction** (to the right). If the pilot believes the illusion of a right turn (which can be very compelling), he/she will re enter the original left turn in an attempt to counteract the sensation of a right turn. Unfortunately, while this is happening, the airplane is still turning to the left and losing altitude. Pulling the control yoke/stick and applying power while turning would not be a good idea–because it would only make the left turn tighter. If the pilot fails to recognize the illusion and does not level the wings, the airplane will continue turning left and **losing altitude** until it impacts the ground.

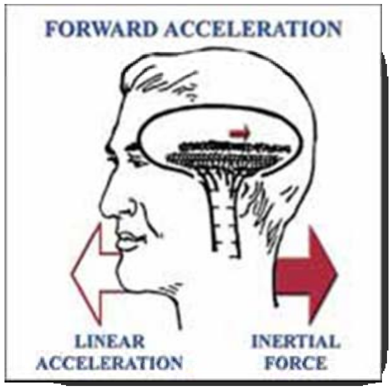
d. **The Coriolis Illusion** involves the simultaneous stimulation of two semicircular canals and is associated with a sudden tilting (forward or backwards) of the pilot's head while the aircraft is turning. This can occur when you tilt you head down (to look at an approach chart or to write a note on your knee pad), or tilt it up (to look at an overhead instrument or switch) or tilt it sideways. This produces an almost **unbearable sensation that the aircraft is rolling, pitching, and yawing all at the same time,** which can be compared with the sensation of rolling down on a hillside. This illusion can make the pilot quickly become disoriented and **lose control of the aircraft**.

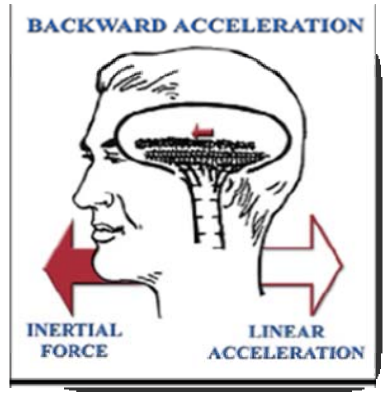
4.2 THE OTOLITH ORGANS:

Two otolith organs, the utricle and saccule, are located in each ear and are set at right angles to each other. The utricle detects changes in linear acceleration in the horizontal plane, while the saccule detects gravity changes in the vertical plane. However, the inertial forces resulting from linear accelerations cannot be distinguished from the force of gravity; therefore, gravity can also produce stimulation of the utricle and saccule. These organs are located at the base (vestibule) of the semicircular canals, and their structure consists of small sacs (maculas) covered by hair cell filaments that project into an overlying gelatinous membrane (cupula) tipped by tiny, chalk-like calcium stones called otoconia

a. Change in Linear Acceleration

The inertial forces resulting from a forward linear acceleration (take-off, increased acceleration during level flight, vertical climb) produce a backward displacement of the otoconia of the utricle that pulls the cupula, which in turn bends the haircell filaments that send a signal to the brain, indicating that the head and body have suddenly been moved forward. Exposure to a backward linear acceleration or to a forward linear deceleration has the opposite effect.





b. Change in Gravity

When the head is tilted, the weight of the otoconia of the saccule pulls the cupula, which in turn bends the hairs that send a signal to the brain indicating that the head has changed position. A similar response will occur during a vertical take-off in a helicopter or following the sudden opening of a parachute after a free fall.

4.2.1 VESTIBULAR ILLUSIONS: (SOMATOGRAVIC - Utricle and Saccule)

Illusions involving the utricle and the saccule of the vestibular system are most likely under conditions of unreliable **or unavailable external visual references**. These illusions include: the **Head-Up Illusion**, **Head-Down Illusion and Inversion Illusion**.

a. **The Head-Up Illusion** involves a sudden forward linear acceleration during level flight where the pilot perceives the **illusion that the nose of the aircraft is pitching up**. The pilot's response to this illusion would be to push the yolk or the stick forward to pitch the nose of the aircraft down. A night take-off from a well-lit airport into a totally dark sky (black hole) or a catapult take-off from an aircraft carrier can also lead to this illusion, **and could result in a crash.**

b. **The Head-Down Illusion** involves a sudden linear deceleration (air braking, lowering flaps, decreasing engine power) during level flight where the pilot perceives **the illusion that the nose of the aircraft is pitching down.** The pilot's response to this illusion would be to pitch the nose of the aircraft up. If this illusion occurs during a low-speed final approach, the pilot **could stall the aircraft**.

c. **<u>The Inversion Illusion</u>** involves a steep ascent (forward linear acceleration) in a high-performance aircraft, followed by a sudden return to level flight. When the pilot levels off, the aircraft's speed is relatively higher. This combination of accelerations produces **an illusion that the aircraft is in inverted flight**. The pilot's response to this illusion is to lower the nose of the aircraft.

5. THE PROPRIOCEPTIVE RECEPTORS:

The proprioceptive receptors (proprioceptors) are special sensors located in the skin, muscles, tendons, and joints that play a very small role in maintaining spatial orientation in normal individuals. Proprioceptors do give some indication of posture by sensing the relative position of our body parts in relation to each other, and by sensing points of physical contact between body parts and the surrounding environment (floor, wall, seat, arm rest, etc.). For example, proprioceptors make it possible for you to know that you are seated while flying; however, they alone will not let you differentiate between flying straight and level and performing a coordinated turn.

6. CONSEQUENCES OF SPATIAL DISORIENTATION:

The Accident as a Situational example

During a visual approach at night and in visual meteorological conditions (VMC) to an airport surrounded by water, you, as first officer, have a very good view of the airport and adjacent land. On the captain's side, it is completely dark; at night over the sea, there are no horizon cues. You see you are too high and too fast, typical of a non-stabilized approach.

Faced with a non-stabilized approach, what would you do?

The captain, as pilot flying (PF), requests clearance from air traffic control (ATC) for a 360-degree left turn to realign with the runway. This is in violation of standard operating procedures (SOPs), but he does not want to go around. The ATC controller authorizes the manoeuvre.

During the tight 360-degree left turn, final preparation for landing is performed — gear and flaps fully extended, landing checklist completed. However, the airplane overshoots the runway. The captain decides to reject the landing and engages full TOGA (takeoff/go-around) thrust, delivering a constant acceleration with a 9-degree nose-up pitch attitude. The controller clears you to climb to 2,500 ft to prepare for another approach. You retract the landing gear.

During the tight turn at low altitude over the sea at night, all visual cues are lost, and both of you concentrate on the external view to reacquire situational awareness.

In a constant acceleration environment provided by the TOGA thrust, the captain turns his head to look outside, trying to get an external cue, while the airplane is pitching up.

Passing over the runway at around 1,000 ft and 191 kt, the aural master warning sounds to indicate a flap-overspeed condition.

Would this aural warning attract your attention to a flap-overspeed situation?

After the alarm sounds, the captain **pushes the controls forward**. During this time, the airplane pitch attitude decreases, and **the airspeed increases** from about 193 kt to 234 kt.

A single aural “SINK RATE” warning is issued by the ground-proximity warning system (GPWS), followed by a repetitive GPWS aural “WHOOP, WHOOP, PULL UP” warning.

The captain requests “flaps up,” moves the controls aft of neutral and then calls for “flaps all the way.” You respond and acknowledge “flaps zero.”

The airplane is destroyed as it hits the water in a 6-degree nose-down pitch attitude at an airspeed of about 282 kt.

Data, Discussion and Human Factors

The accident report showed there was not a single cause to this accident, but **several combined contributing factors** led to the fatal outcome. Those factors are summarized below for the sake of completeness, and this situational example will focus on human factors issues such as the disorientation that led the captain **to perceive wrongly that the airplane was pitching up** and consequently led him to command and maintain a pitch-down attitude.

Active failures

Non-adherence to standard operating procedures (SOPs). The captain, as PF, did not follow airline procedures, resulting in the following:

i. A higher than standard speed for start of descent and initial approach;
ii. A non-stabilized approach;
iii. The low-altitude orbit as a nonstandard manoeuvre to the runway; and,
iv. The incorrectly performed go-around.
v. The first officer did not object or call the captain's attention to his non-adherence to the procedure.
vi. The controller allowed a shortcut — a 360-degree turn above the airport — and did not follow the procedure for the path leading to a stabilized approach from the final fix.
vii. During go-around, the crew apparently experienced spatial disorientation, which may have caused the captain to wrongly think the airplane was pitching up.
viii. Despite the GPWS warnings, the crew did not adequately respond.
ix. Analysis of the cockpit voice recorder (CVR) data showed the crew did not perform as a team, due to inadequate airline training in crew resource management (CRM), SOPs, controlled flight into terrain (CFIT) and GPWS.

Disorientation: Somatogyral/Somatogravic illusions

During the approach in night conditions, the crew had on one side a very bright view of the airport and a landmass and on the other side a completely dark area over the water.

Focusing on the visual approach, the **crew may have lost visual cues** and may have **experienced visual illusions and disorientation** when initiating the tight 360-degree turn over water, after the non-stabilized approach.

The first officer, as pilot not flying (PNF), was **not monitoring his instruments** and **did not use proper CRM techniques** to gain the captain's attention.

In addition, TOGA provides **constant acceleration**. In the **absence of visual cues** such as the horizon, this **constant longitudinal acceleration fooled the captain's vestibular system** into interpreting this as horizontal flight at constant speed.

The otholitic hairs send the same signal when subject to constant longitudinal acceleration or to upward motion — or likewise when subject to deceleration and downward motion. An example is **the leans**: with a slow roll rate, a **pilot may perceive the aircraft as still flying straight and level** although the **attitude indicator shows the aircraft to be, in fact, banking**.

Involved in a tight climbing turn, the pilot, when turning his head, may also have been subject to the **Coriolis effect**, which led to a **loss of spatial orientation and to vertigo.**

Subject to **a "false climb" interpretation**, the captain reacted by pushing the control column forward and maintaining the nose-down pitch attitude until he started to realize the reality of the situation. By then, it was too late due to the airplane's low altitude.

7. Prevention Strategies

a. Lines of Defence

i. The first precaution to avoid an accident is to **not put oneself in a nonstandard situation.** The resulting situation may not appear to be risky at the beginning, but, as we know, accidents often result from multiple contributing factors. Allowing the situation to develop in the first place generates unnecessary risks.

ii. Further, **the quality of the approach briefing** helps to focus on the following: Ensuring that one crewmember maintains visual contact with the runway lights. Task sharing and workload management between the crewmembers. Effective coordination with the ATC. Being prepared for a go-around.

iii. Remembering **the consequences of visual illusions** when there is a mismatch between the real world and what is sensed.

iv. Maintaining **continuous instrument monitoring** to counter the onset of vestibular system illusions.

v. When realizing that situational awareness is lost, **applying strict SOPs** such as precise go-around procedures with task sharing, callouts, go-around altitudes, speeds, headings and minimum safe altitudes.

b. Quality of briefings

Operational procedures require a go-around to be flown at constant speed and without any acceleration with one flap retraction. The acceleration and cleanup should be done at a higher altitude. This is to ensure that a correct go-around is performed and associated procedures follow.

In general, there are no go-around procedures that require a sustained turn because, from a human factors point of view, crews might suffer Somatogyral (Coriolis) disorientation as well as Somatogravic (false climb) disorientation.

Avoiding shortcuts and strict adherence to procedures help to avoid creating risky situations. This is the principal reason for approved SOPs.

c. Adherence to SOPs

Adequate CRM training helps to achieve an effective balance among crewmembers. Emphasis on cross-checking and clear task sharing provides a basis for sound attitudes. In our example, the first officer's task was to monitor the instruments to effectively and adequately inform his captain. The captain's role in relation to his first officer was to encourage him to speak.

d. Improved training in CRM and visual illusions

Training to prevent Somatogravic illusion is almost impossible, but information and sensitization can help pilots recognize its onset and prepare to face it.

The only known way to regain proper orientation is to focus on the airplane's instruments to rebuild a correct mental image of the situation.

8. Conclusion

i. The pilot should understand the **elements contributing to spatial disorientation** so as to prevent loss of aircraft control if these conditions are inadvertently encountered.

ii. The following are certain basic steps which should assist materially in preventing spatial disorientation.

iii. Before flying **in less than 5 Kms** visibility, obtain training and maintain proficiency in airplane **control by reference to instruments**.

iv. When flying **at night** or in reduced visibility, **use the flight instruments**.

v. If intending to fly at night, **maintain night-flight currency**. Include cross country and local operations at different airports.

vi. If **only Visual Flight Rules-qualified**, do **not attempt visual flight** when there is a possibility of getting trapped **in deteriorating weather.**

vii. If you experience a vestibular illusion du ring flight, **trust your instruments and disregard your sensory perceptions.**

viii. Study and become familiar with **unique geographical conditions** in areas proposing to operate.

ix. Check **weather forecasts** before departure, en route, and at destination. Be alert for weather deterioration. Do not attempt visual flight rule flight when there is a possibility of encountering deteriorating weather. .

x. Discipline helps: **adherence to SOPs** helps improve safety.

xi. In the absence of visual cues, referring to the instruments to get a correct mental image and continuous instrument monitoring may help to counter vestibular disorientation. **Rely on instrument indications** unless the natural horizon or surface reference is clearly visible.

xii. Adequate **crew communication** is a critical contributing factor to risk reduction as well as effective **coordination with ATC**.

xiii. Remain **prepared for a go-around** while remaining aware of possible visual illusions.

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