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Inadequate Visual References in Flight Pose Threat of Spatial Disorientation

One form of spatial disorientation can occur at low altitude in visual meteorological conditions (VMC). The somatogravic illusion gives the pilot the false sensation that the aircraft is flying at an excessively high angle-of-attack and is therefore at risk of stalling.

FSF Editorial Staff

Generally, no professional pilot intentionally puts his aircraft into an unusual attitude. But aircraft can fly into unusual attitudes when pilots get disoriented, and it is not always the novice pilot who can be temporarily disoriented.

The most accurate sensory information available to the pilot about aircraft attitude and motion is the visual information provided by the earth's horizon, the aircraft's flight instruments or both. When this information is not used — for example, when the visual horizon is obscured by darkness or weather, or when the pilot's attention is distracted from the attitude instruments for a short time — the pilot may become temporarily disoriented.

The temporary inability of the pilot to determine his (and the aircraft's) true motion or attitude relative to the earth or his surroundings is called spatial disorientation (SD).

SD can take many different forms. The most familiar is probably vertigo, a dizziness or spinning sensation caused by a conflict between what the pilot's senses tell him and what the aircraft's attitude instruments indicate. "Nothing can be done immediately to make these vertigo sensations go away if they are experienced in flight," wrote Stanley R. Mohler, M.D. "But with increasing experience, pilots learn to disregard these incoming sensations and to fly the aircraft by reference to the instruments."[1]

The somatogravic or "false-climb" illusion may be a less-known form of SD; but, inasmuch as it often occurs near the ground and can cause a pilot to mistakenly bring the nose of the aircraft down, the result can be controlled flight into terrain.

(See examples of accidents involving somatogravic illusion: "DC-9 Captain Possibly Affected by 'False-climb' Illusion," page 2; and "Charter Pilot Flies Aircraft into Ground After Dark-night Take-off," page 4.)

Millard Reschke, Ph.D., of the U.S. National Aeronautics and Space Administration (NASA)/Johnson Space Center (JSC) Space Biomedical Research Institute, Houston, Texas, U.S., states, "The knowledge of where our bodies are, relative to the environment, is a complex function involving the brain's ability to integrate information from virtually every sensory system."[2]

The body's orientation senses comprise the eyes (vision); the inner ear (vestibular system); and the muscle, tendon and organ proprioceptors, which are sometimes the origin of the "seat of the pants" sensation. The sense of sight is not always predominant; that is, conflicting messages from other senses tend to prevail when there is loss of outside visual orientation. With instrument training, these conflicting messages can be disregarded.

The sensory organs, developed over thousands of years of ground dwelling, can be misinterpreted. For example, the movement of an external object may be construed by the observer to reflect movement of his own body. An example can be found in an automatic car wash, where the backward

DC-9 Captain Possibly Affected by "False-climb" Illusion

The USAir DC-9-31 was inbound to Charlotte/Douglas International Airport in Charlotte, North Carolina, U.S., on July 2, 1994. Aboard were 52 passengers and five crew members.

The general weather at Charlotte was reported as a ceiling of 1,400 meters (4,500 feet) with visibility of 10 kilometers (six miles) in thunderstorms, light rain showers and haze in daylight. The temperature was 31 degrees C (88 degrees F).

The flight had taken off from Columbia, South Carolina, U.S., at 1815 hours. It made its first radio contact with Charlotte at about 1830 and was vectored by Charlotte approach control to an instrument landing system (ILS) approach to Runway 18 right.

At 1836, while on the ILS approach at an altitude of about 1,200 meters (4,000 feet), the flight crew saw the runway and were cleared to descend to and maintain an altitude of 700 meters (2,300 feet) for a visual approach to the runway. About five minutes later, on final approach, the cockpit voice recorder (CVR) recorded a wind-shear warning from Charlotte tower.

1841:06	Tower	wind shear alert northeast boundary winds one nine zero at one three

About the same time, the airplane encountered very heavy rain, and the windshield wipers were turned on.

Sixty-eight seconds later, at a pressure altitude of about 290 meters (950 feet) — or about 60 meters (200 feet) above the ground — the captain elected to abort the approach. The CVR transcript contains the following exchange (CAM-1 is the captain, CAM-2 is the first officer, who was the pilot flying):

1841:58.9	CAM-2	there's, ooh, ten knots right there
1842:06.4	CAM-1	OK, you're plus twenty
1842:14.0	CAM-1	take it around, go to the right
1842:17.7	CAM-1	max power
1842:18.5	CAM-2	yeah max power
1842:19.4	CAM-2	flaps to fifteen
1842:22.0	CAM-1	down, push it down

The transcript of the flight data recorder (FDR) indicated that during the next seven seconds the airplane entered a right bank and that the airplane's pitch attitude transitioned from 15 degrees nose up to five degrees nose down. Beginning at 1842:28, in rapid sequence, the ground-proximity warning system (GPWS) warning sounded, the sound of the stick shaker was heard and the aircraft struck the ground.

Four persons received minor injuries, including the captain, first officer, one flight attendant and one passenger. Two flight attendants and 14 passengers were injured seriously. The remaining 37 passengers died in the accident.

The official report of the accident, prepared by the U.S. National Transportation Safety Board (NTSB), said, "Examination of the circumstances during the last minute of the flight strongly suggest that the captain, upon losing his visual cues instantaneously when the airplane encountered the heavy rain, could have experienced a form of spatial disorientation.

"The disorientation might have led him to believe that the aircraft was climbing at an excessively high rate and that the pitch attitude should be lowered to prevent an aerodynamic stall.

"The [NTSB] believes that since the captain was not the pilot flying the airplane, he was a prime candidate for the effects of somatogravic illusion for the following reasons: His visual and mental focus was outside the airplane during the majority of the approach to Runway 18R; he was not using the primary flight instruments for spatial orientation; his visual cues were no longer available during the encounter with heavy rain; and the accelerative forces resulting from the power application and the 'G' forces associated with the pitch of 15 degrees nose up and a roll of 17 degrees right wing down, in combination, produced physiological sensations that the captain might have interpreted as excessive ... ."[3]♦

Source: U.S. National Transportation Safety Board

movement of the rotating brushes creates for the car's occupant a powerful illusion that the car is moving forward.

The limitations of our senses become more apparent when we leave the ground in an aircraft.

The vestibular (inner ear) system is especially important in flight because it is the sense that determines balance. The vestibular system comprises two structures: the semicircular canals and the otolith organs (Figure 1, page 3). These structures together provide information to the brain about the position and movement of the head. The information helps to maintain equilibrium and to keep the eyes fixed on an object while the head is turning.

The semicircular canals and the otolith organs are also responsible for the illusions that can cause a person to temporarily become disoriented in relation to the surrounding world.

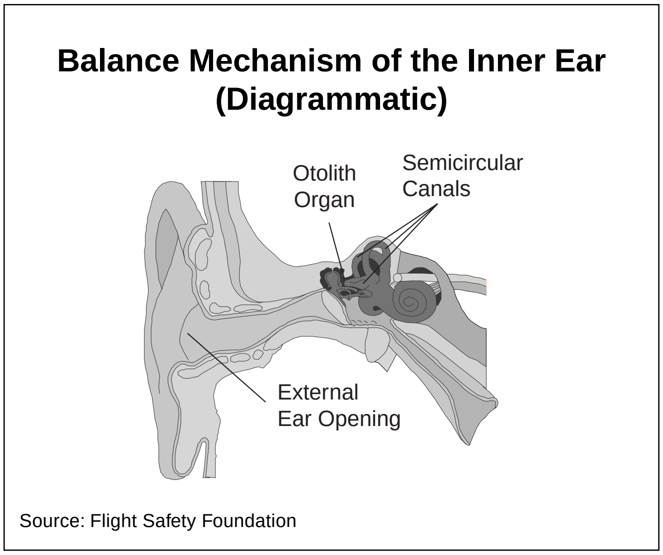


Figure 1

The semicircular canals are small, bone-lined, fluid-filled semicircular tubes in the inner ear; they sense angular acceleration, such as rotation of the head. There are three canals, each aligned on a different axis corresponding to pitch, roll and yaw. Each canal has a tuft of sensory hairs extending from the canal wall into the fluid.

When the head is stationary, the hairs stand erect and indicate to the brain that no rotational acceleration is occurring (Figure 2A). When the head is rotated about one or more of the three axes — as in an aircraft turn, for example — inertia causes the fluid in the canal to lag the movement of the head; the resulting movement differential between the fluid and the canal walls bends the hairs and signals to the brain that the head is being accelerated rotationally relative to the earth (Figure 2B).

"It takes about one degree per second of acceleration to stimulate the semicircular canal sensory organ," wrote Mohler. "In other words, in order to keep stimulating these canals with turning, one has to increase the acceleration to two degrees per second by the end of the second second, and to three degrees per second by the end of the third second, and so on."[1]

If, instead, the rotation of the head continues at a steady rate (the rate of turn is held constant), the fluid will eventually "catch up," and the hairs will return to an upright position, sending a (false) message to the brain that the rotation has stopped (Figure 2C). Likewise, if the rotation is stopped suddenly, the fluid will continue to move for a short time, bending the hairs and creating the illusion that the head is rotating in the opposite direction (Figure 2D).

The otolith organs sense linear acceleration and static changes in the position of the head relative to gravity. Otolith organs are key to the somatogravic illusion.

The word "otolith" derives from the Greek language, in which "otos" means ear and "lithos" means stone.

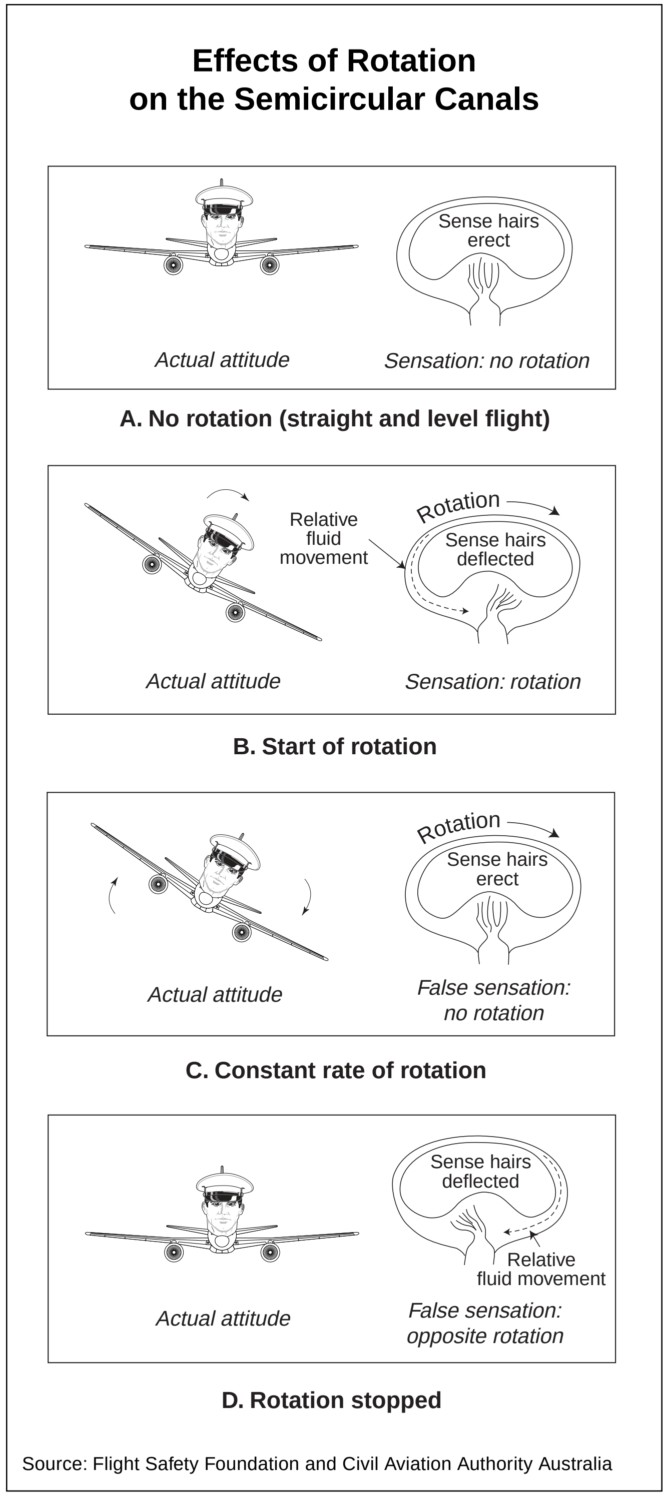


Figure 2

The otolith organ has sensory hairs with small calcium carbonate crystals attached to the ends (Figure 3, page 4). These hairs bend when affected by gravity or flight acceleration or deceleration forces. The crystals, by adding mass, increase the hairs' directional sensitivity to movement.

Dougal Watson, M.D., said, "The action of gravity on these otolith crystals provides information concerning head

Charter Pilot Flies Aircraft into Ground After Dark-night Takeoff

The Cessna 310R, a twin-reciprocating-engine, light aircraft, was on a night charter flight for Athabaska Airways. The airplane took off from Sandy Bay, Saskatchewan, Canada, about 2130 hours on Oct. 12, 1993. Shortly after takeoff, the aircraft flew into the ground about 0.8 kilometer (0.5 mile) beyond the upwind end of Runway 05. The aircraft's attitude at impact was wings level and a low climb angle. The pilot and three passengers were killed.

The official Transportation Safety Board of Canada (TSB) accident report said, "The pilot established, and the aircraft remained in, a very shallow climb after takeoff and struck trees during the initial departure, while in controlled flight prior to reaching cruise climb speed."[4]

The accident investigation cited as contributing factors the poor ground and sky illumination, the absence of illumination from landing lights and deviation from the recommended night-departure profile.

There were no other contributing factors. A complete teardown of both engines showed no pre-existing mechanical faults that would have contributed to a loss of engine power. There were no mechanical discrepancies that would have affected the aircraft's performance. Weight-and-balance was within prescribed limits.

The weather on the night of the accident was near freezing, with light winds. The ceiling was estimated at 1,000 meters (3,050 feet) above ground level. There was no fog or other low-level atmospheric obstructions to visibility.

The runway had threshold and runway-end lights, and there were low-intensity lights along the runway edge, but beyond that there was scant illumination.

The accident report said, "There are very few ground lights northeast of the aerodrome, and witnesses agreed that, at the time of the accident, there was little or no illumination from either the lights of the community or from the night sky."

The pilot held a commercial pilot license and an instrument rating. He had 4,700 hours of flight time, 500 of which were in the Cessna 310. But, the accident report said, "The pilot's twin-engine instrument flying performance was recorded as weak during training and previous flight tests."

The report discussed the pilot's behavior. "The pilot had developed a habit of establishing a shallow climb angle after takeoff and of climbing out after reaching cruise climb speed," said the report.

The terrain beyond the departure end of Runway 05 consisted of low rolling hills. The report said, "These hills are forested with ... trees which rise to an average height of approximately [nine meters to 12 meters (30 feet to 40 feet)] above ground level. The tops are well below the obstacle limitation surface that would normally be applied to the departure end of a certified airport."

The report said of the false-climb perception, "Somatogravic illusion is an erroneous sensation of pitch (rotation in a vertical plane) caused by linear acceleration; it is most common during rapid acceleration ... ."

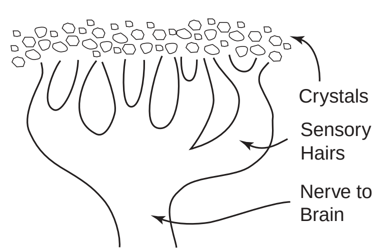
In the findings, the report said, "Somatogravic illusion may have adversely affected the pilot's performance during the acceleration stages of the takeoff and initial climb."♦

Source: Transportation Safety Board of Canada

position. Moving an otolith organ from the horizontal [tilting the head] causes gravity to pull on the crystals and bend the sensory hairs. This bend in sensory hairs is usually interpreted by the brain as a change in the orientation of the head [Figure 4, page 5].

"When linear acceleration occurs in the plane of an otolith organ [and the head remains upright], the crystals lag a little due to inertia. This lag causes the sensory hairs to bend and information concerning the acceleration to travel to the brain. After a period at constant speed, the crystals 'catch up,' the hairs stand erect, and no acceleration is sensed. When you slow from a constant speed, the crystals tend to shoot ahead due to their inertia. This causes bending of the sensory hairs [in the forward direction] and sensation of deceleration [Figure 5, page 5]."[5]

Structure of an Otolith Organ



Source: Flight Safety Foundation and Civil Aviation Authority Australia

Figure 3

If a visual takeoff and climb are attempted when ground visual cues are inadequate or unavailable — for example, on a moonless night, or directly into the setting sun, or with an obscured windshield — acceleration, which causes the sensory hairs to bend backward, may be interpreted by the brain as an upward tilt of the head (Figure 5C), inducing the pilot to believe that the aircraft is pitched upward and therefore flying at a dangerously high angle-of-attack.

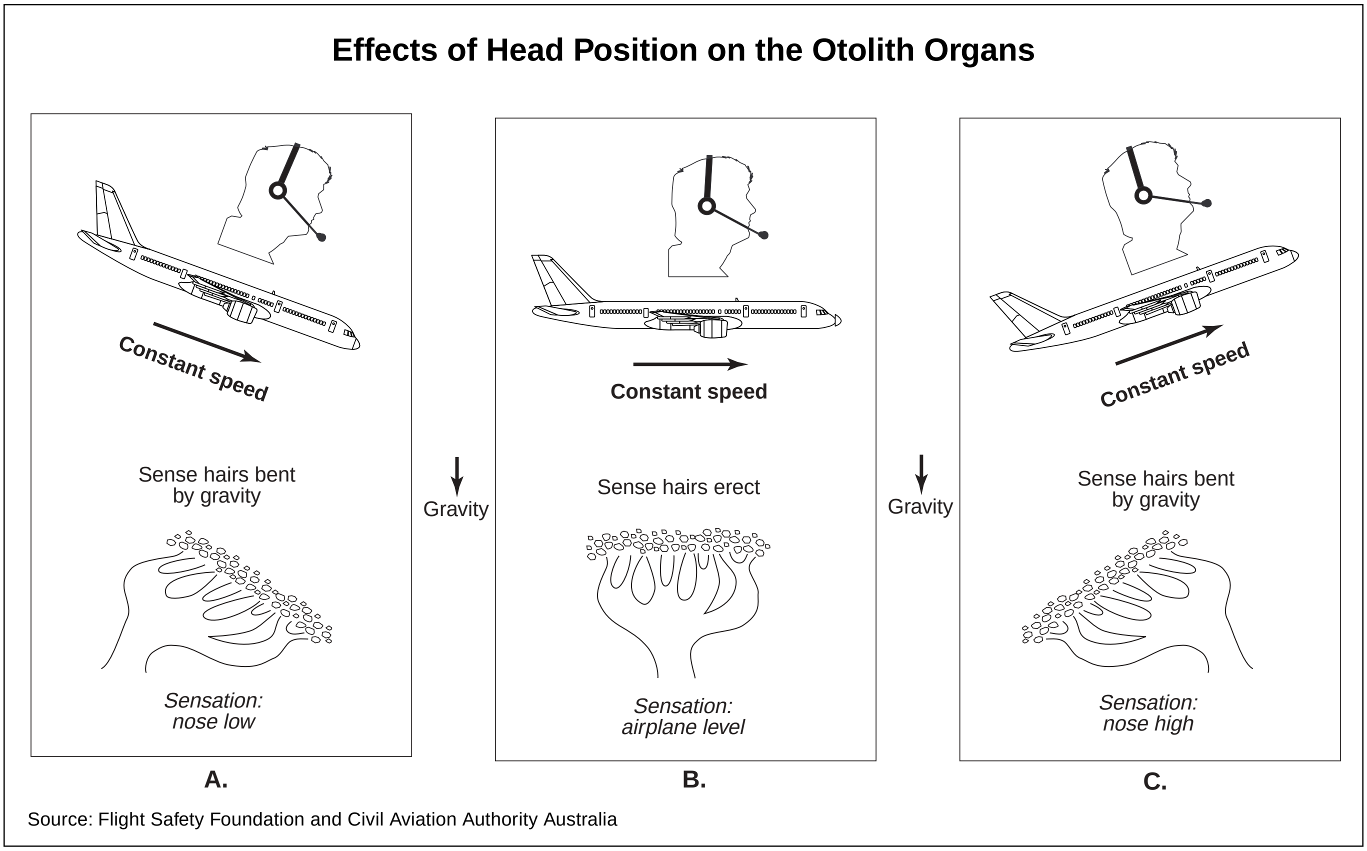


Figure 4

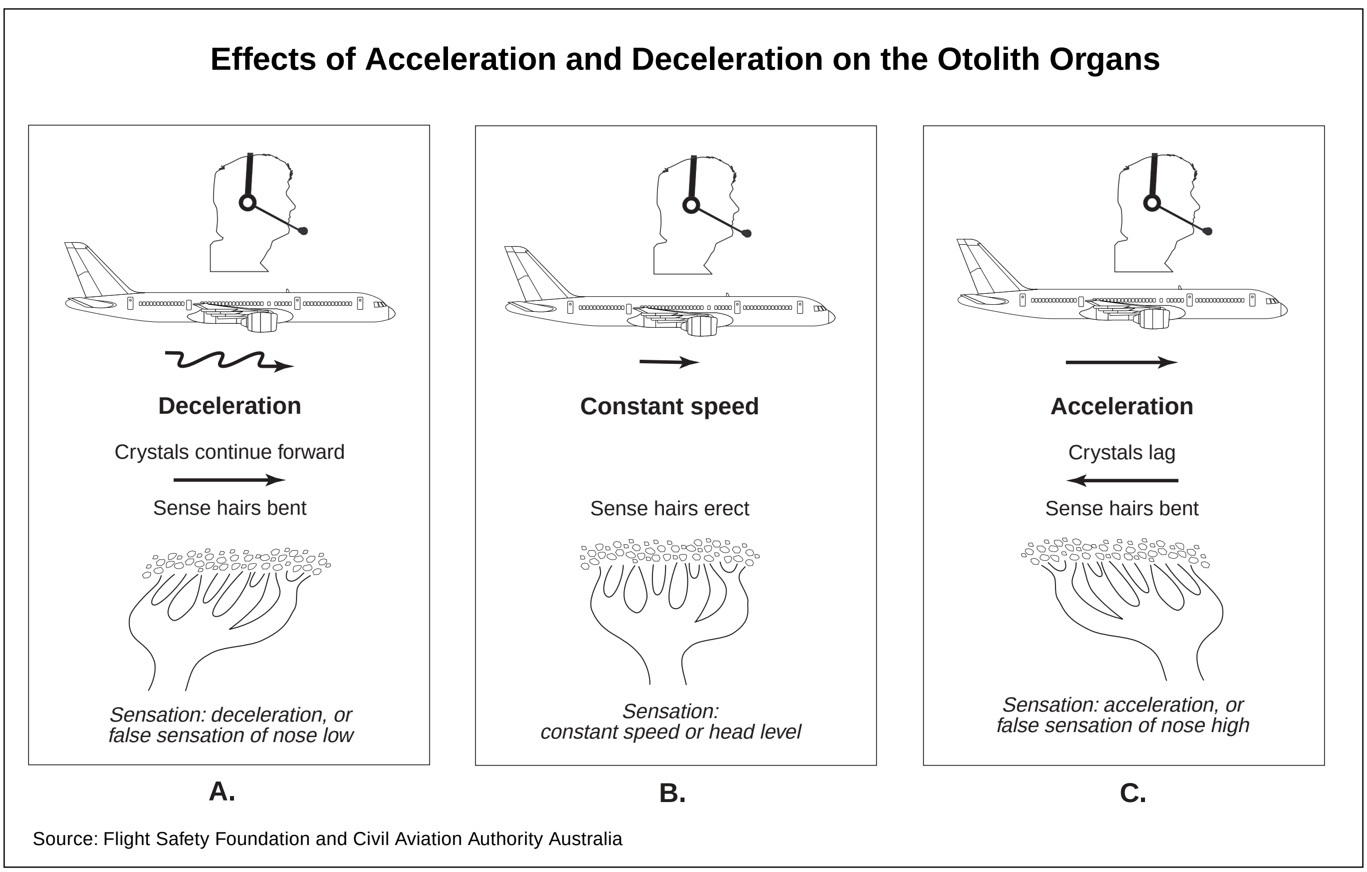


Figure 5

Likewise, deceleration can create a "reverse" somatogravic illusion, or the false sensation that the aircraft is descending. The forward movement of the sensory hairs caused by the deceleration is interpreted by the brain as a downward tilt of the head (Figure 5A). If the pilot reacts by raising the aircraft's nose, the aircraft will slow and further heighten the illusion. The possible result is an aerodynamic stall.

Allen Schwab discussed the airborne pilot's reaction to SD. He wrote, "Because we may all be victims of spatial disorientation from time to time, it's downright healthy to admit to being temporarily disoriented. If possible, a pilot can transfer aircraft control to the other pilot before he gets into trouble. There's no excuse to suffer under a disoriented state while sitting next to a perfectly capable pilot. A single-pilot situation is another matter. Remember to use the autopilot if the flight instruments are functioning normally."[6]♦

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Further Reading from FSF Publications

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