THE PROBLEM OF SPATIAL DISORIENTATION

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In the early days of military aviation and through World War I it was an accepted concept that a sensitive labyrinthine system was essential to proper orientation in flight. Following is a quotation from an outstanding otologist of that era: "Without functioning internal ears it is impossible for an individual to be a good bird-man. . . . It is highly probable that many an aviator has gone to his death because, unknown to him, he did not possess a normal ear mechanism." Today, it is known that it is the functioning of this "normal ear mechanism" which has actually been the cause of untold numbers of airplane crashes. How can this be true? Why should a normal physiological function present one of our major safety hazards under certain conditions of flight?

A recent study has indicated that spatial disorientation or "pilot's vertigo" was responsible for 14% of the fatal aircraft accidents in one of the major overseas commands of the United States Air Force. Review of all major aircraft accidents in the Air Force reveals that disorientation of the pilot is involved in more than 25% of cases in which physical, physiological, and pathological factors are implicated.

All disorientation accidents are not, of course, the exclusive result of labyrinthine perceptual difficulties. The sensory illusions of flight which are productive of spatial disorientation are manifold. These aberrations in the perceptual functions of the pilot which result in a state of disorientation may be divided into two categories, visual illusions and illusions of attitude and motion. By far, the most important are illusions of attitude and motion. These are mediated through the nonauditory labyrinth, including the semicircular canals and the otolith organs of the utricle and saccule. The means...
by which the illusory cues of vision and the labyrinth are productive of spatial disorientation in flight are multiple and complex; however, almost every case of "pilot's vertigo" can be explained on a rational basis through an analysis of the normal visual or labyrinthine perceptual function.

Visual Illusions as Causes of Disorientation

A classic visual illusion which may occur in flight is that of autokinesis. This occurs under conditions of darkness and a single point source of light which is an inadequate visual frame of reference for fixation. The spontaneous, rhythmical movements of the eyes under this circumstance result in the illusion of movement of the light. This has, on occasion, been a cause of collision accidents in night formation flying when only one light was used on lead aircraft. The solution to this problem is to use more than one light for formation flying, which is the present procedure.

There are many other types of visual illusion in flight which may produce serious disorientation. Slanted banks of cloud used as a horizon reference can result in an unusual attitude of flight. Very dark nights with no moon and only scattered, infrequent lights on the ground can result in the pilot's mistaking the ground lights for stars and vice versa; this can produce extreme disorientation resulting in unusual attitudes, including inverted flight. Another type of visual illusion, described by Coceyut,

Illusions of Attitude and Motion as Causes of Disorientation

These visual illusions seem formidable enough when considered in relationship to the exacting and precise requirements of jet flight. They are, however, of minor importance when compared to the frequent and overwhelming disorientation effects of the illusions of attitude and motion mediated principally through the labyrinthine system. The reason for this is that normal visual perception, even in flight and when used appropriately, is almost 100% reliable, whereas labyrinthine sensations in flight are, on the contrary, almost 100% unreliable as a means of orientation in space. The labyrinthine apparatus was designed to function in reference to a stable platform, the earth's surface. When used on a very unstable platform, the airplane, with freedom of motion about three axes in three-dimensional space, it assumes the role of the perfect organ of perceptual confusion. This perceptual confusion is the direct result of false sensory cues of motion or position produced by the labyrinthine system in response to the multiple stimuli of the varied accelerations of flight.

Reasons for Erroneous Sensations.—Erroneous cues emanate from both functional subdivisions of the nonauditory labyrinth. Sensations from the semicircular canals may be erroneous for two basic reasons. First, the canals are stimulated by angular acceleration which displaces the cupula as a result of endolymphatic inertia. This produces a sensation of rotation only so long as the cupula is displaced. It is possible for the angular acceleration to be reduced, removed, or reversed while the initial direction of rotation remains the same; thus the sensation incident to changes in displacement of the cupula by varied angular accelerations may bear no uniform relationship to the actual direction of rotation. The second reason for inappropriate cues from the semicircular canals is that the cupula acts as a damped pendulum system and has a slow recovery from a displaced position to its neutral position after an acceleration. This results in an after-sensation of rotation for a minute or longer after the acceleration and even after rotation has stopped. Also, there may occur a second and third, or even a fourth, after-sensation of rotation, each alternating to opposite directions. It is thought that these sensations result from chemical after-effects similar to the after-image in vision. The otolith organs are prone to produce positional cue errors because they are stimulated by both gravity and rectilinear accelerations without being able to distinguish between forces due to gravity and those due to other accelerations.

To some extent the labyrinthine system is aided by other senses in its role as "major-domo" of spatial disorientation. Perceptual information from proprioceptive sensory end-organs in muscles, tendons, skin, and viscera frequently is not in consonance with the true direction of terrestrial gravitational forces, the stimulus to which they are normally attuned. Further, there is often marked conflict in the interrelations among the three modalities of perception in the triad of equilibrium; vision, the nonauditory labyrinth; and the kinesthetic, external pressure, and visceral sensibilities (somesthetic and visceral proprioceptive groups). Besides this intermodality disagreement, intramodality conflict may even occur; as for example, the conflict between the semicircular canals and the otolith organs when the position of the head is changed during the primary
post-rotational after-sensation. This conflict in itself is productive of marked confusion, forced postural reflexes, and marked autonomic effects. Conflict can also occur between kinesthetic and external pressure sensation.

An additional and very important complicating factor in this gamut of interacting perceptual modalities is that induced by head movements relative to existing body motion and position. Head movements induce two reactions of importance to the pilot: first, postural reflexes which may adversely affect the fine manual coordination necessary for proper manipulation of aircraft controls and, second, the Coriolis reaction. The Coriolis reaction results from movements of the head at right angles to the plane of an existing rotation of the body. It produces confusion and marked autonomic responses similar to those caused by changes in head position during the after-sensation of rotation. Finally, the interaction of the above-considered visual, tactile, and primary and secondary proprioceptive mechanisms with central integrative functions and superimposed volitional, emotional, and judgment factors creates an imposing psychophysiological hodgepodge.

It may seem that this discussion has led to what is apparently a hopeless jungle of confused verbiage. If so, it is certainly equaled by the overwhelming confusion of the hapless pilot who is victimized by his so-called prime organ of balance and suddenly finds himself in the terminal phase of complete spatial disorientation from which it is impossible to recover before fatally crashing into the ground. Yet, it is realized this is exactly what one might expect when consideration is given to the vast central network which this tiny organ of balance bombards with erroneous impulses. The vestibular nerve leads to the complex of vestibular nuclei in the brain stem, from whence direct or relay connections reach almost every part of the central nervous system, including the eye muscle nuclei, motor nuclei at all levels of the cord, vast areas of the cerebellum, reticular nuclei of the midbrain, the reticular formation of thepons and medulla, and the cerebral cortex. Thus the complexity of the problem of spatial disorientation is heralded by the complexity of the neurophysiological mechanisms and anatomic structures involved.

Types of Illusions of Attitude and Motion Causing Disorientation.—From a practical aspect the disorientation producing illusions of attitude and motion, mediated primarily through the labyrinthine system, may be simple or complex, subtle or overwhelming. These illusions will vary with the individual pilot and with the conditions of flight; hence the varieties of so-called vertigo experiences induced in pilots are almost numberless. Illusions can occur under almost any flight condition but are more frequent and more productive of disorientation under conditions of reduced visibility, such as severe weather or night flying.

Misinterpretation of Gravitational Forces: When an illusion is simple it may involve false sensations or false interpretation of cues from only one part of the labyrinth. For example, the otolith organs are stimulated by linear accelerations and the sensation produced is that of a certain position in space. The interpretation of this position sensation during flight is variable and may be incorrect for several reasons. First, the acceleration of gravity combines with the variable accelerations of powered flight to produce a resultant force not indicative of the actual position. The resultant force is interpreted by the otolith organs and therefore the position sensation is in error. This may result in misinterpretation of one degree or the same. I was then in an aircraft equipped with a balance beam which indicated that I was stationary and that the aircraft was in a dive. The Coriolis force, however, produced an illusion of a roll to the right. In this instance gravity was not the sole determinant of the illusion. Second, the sensations received from the otolith organs may be interpreted in relationship to variable references of past experience. Thus, strong centrifugal forces produced by such varied maneuvers as loops and dives may stimulate the otoliths in an identical manner and in a manner also identical to that of gravity. Therefore the individual can have sensations of being upright when inverted, of climbing while turning, or of diving during recovery from a turn. The otolith sensations in this instance are frequently reinforced by other proprioceptive sensations. Further, alternating threshold and subthreshold accelerations may produce confusion with respect to one's position in space. A type of disorientation called "the lean" is produced by this mechanism.

An example of the disorienting effects of misinterpretation of gravitational forces resulting from certain flight maneuvers follows:

Pilot BA. Total hours: 1,200. Jet hours: 650. Recent incident. F84F.—On a night formation flight (Africa, very dark) two F84F aircraft. I was chase pilot on a night check-out. Lead aircraft had no light on wing tip in the dim position so I requested that he go to bright. Then I moved out in order that the excessively bright white light on the fuselage wouldn't blind me. Somehow I got into a slight climb and had to drop my left wing to keep the leader in sight. I checked my altimeter and saw 12,000 ft. (flight level was 20,000 ft.) The lead aircraft appeared well below me and I was having to pull power off to stay with him. I advised him on the radio that I was at 12,000 ft. and that he appeared dangerously low. He replied that he was flying on instruments and advised me to follow him in a steep dive following a barrel roll around him and was nearly inverted. I recovered at 3,000 ft., 17,000 ft. below the leader.

It is obvious that at one point pilot BA was looking up when he thought he was looking down.

Erroneous Sensation of Rotation: Illusory effects produced by the semicircular canals alone occur and result from angular accelerations of flight which vary in magnitude and direction; these accelerations frequently become dissociated from the
actual direction of rotation. As a result the illusion produced is one of reversal or other confusion of the direction of rotation. Different axes of rotation may be involved, and sudden change from one axis to another may occur as a result of the Coriolis effect mentioned before.

A classic example of serious disorientation due to erroneous sensation of rotation reversal is demonstrated in the so-called graveyard spin, the mechanism of which is as follows: A pilot in a spin to the right will have an initial sensation of spinning to the right due to the angular acceleration which initiates the spin. This sensation will continue only so long as the cupula remains displaced by acceleration plus the time lag of returning to its neutral position. Therefore, if a stable spin develops with no increase in rate of spin or if the pilot takes some corrective action and increased spin rate is prevented he will have a sensation of not spinning at all during a time when he is actually still spinning to the right. If he takes more vigorous action the spinning to the right will be suddenly slowed, which is in effect an angular acceleration to the left. This will then displace the cupula in the opposite direction and produce a sensation of spinning to the left. This sensation of left spin may occur before the right spin has been fully recovered from or just at the point of recovery. As a result of the sensation of left spin, the pilot will then make correction for a left spin, which he is not actually in, and thus reenter the original spin to the right. Depending upon the time available to sort things out, the pilot may run out of altitude and crash into the ground. This type of disorientation is even more critical and confusing when the spin is inverted, and it can result in a crash in perfectly clear weather.

The aerodynamic qualities of present-day high-performance aircraft make spin recovery exceedingly difficult even in the absence of severe disorientation. Also, the rapid rate of descent telescopes the criticalness of the time factor. Further, inverted and unstable spins are more frequent in high-performance aircraft and erratic post-stall gyraions sometimes occur which may completely baffle the ingenuity of the most astute test pilot. The general idea today is not to get into a spin.

Disorientation due to illusions of turning or rolling is frequent. These are usually mild illusions, readily overcome by instrument reference; however, some can be serious and result in complete loss of control of the aircraft. Some examples of this type illusion follow:

PILOT N. TOTAL HOURS: 530. JET HOURS: 300. RECENT INCIDENT. F86.—I was flying no. 2 in two-ship (F86F) formation in night weather. During left penetration turn I thought I was turning right and when we rolled out I felt as though we were inverted. I kept on flying the wing and took a glance cross-check of my instruments and finally everything straightened out.

PILOT AL. TOTAL HOURS: 1,200. JET HOURS: 500. RECENT. F86F.—I had a sensation of rolling with result that I rolled in opposite direction. I was leader of section of two aircraft in GCA in clouds at 5,000 ft. and had just rolled out of 180-degree procedure turn. Started to roll in opposite direction but instruments indicated no roll so I ignored sensation and stayed on instruments.

PILOT B. TOTAL HOURS: 900. JET HOURS: 500. F86 TRANSITION.—In three-ship formation flight in day weather. Cloud base 700 ft. topped at 35,000 ft. I was flying in F86 and this was my first formation flight in weather. I had never had a serious case of vertigo before. The formation was just rolling out of a 450-degree left climbing turn and went into clouds. The visibility in the clouds was about 500 yd. and I saw the rest of the section but was disoriented. I didn’t go on the dials right away because I was afraid of collision. I had a sensation of turning to the right and therefore corrected to left by reflex; as I did this I became confused and felt that the formation was above me and that I was looking up at them. Flight leader called and told me to go on “gauges” and that I was climbing in an inverted position. I was thoroughly confused but finally did get on instruments.

By this time my airspeed was building up and apparently I was in a dive from a split S. I immediately put out speed brakes and reduced power as I broke through clouds and saw the ground coming up fast. I had already pulled back on the stick. I blacked out but recovered on the deck. I had a 9/10 g pull-out.

Coriolis Acceleration: Disorientation due to the Coriolis effect has been mentioned. Following are examples of disorientation after head movements which probably represent Coriolis acceleration:

PILOT BH. TOTAL HOURS: 2,050. JET HOURS: 800. TIME NOT RECORDED. T33.—I was in the back seat of a T33 on a single-ship weather flight. We were in considerable turbulence at altitude and I was bending over to tune in the radio compass; when I sat up straight I became extremely dizzy and disoriented. I looked at the instruments to see what was going on and could not believe them. I am convinced that I couldn’t have “hacked” it if the other pilot hadn’t been there.

PILOT BJ. TOTAL HOURS: 700. JET HOURS: 400. RECENT. F86D.—On a GCI after completing a turn to proper heading I tried to visually make contact with another aircraft and upon looking back at the instruments I thought I was upside down in a slight dive, at first glance at altitude gyro. I started to roll the aircraft but stopped to recheck gauges. Aircraft was actually in normal attitude in a slight climb. I felt that I needed more instrument practice.

PILOT BJ. TOTAL HOURS: 2,600. JET HOURS: 300. JET TRANSITION. TYPE OF AIRCRAFT UNKNOWN.—I was leading an element in a night formation flight. I had only a few hours in jets. I got into a diving turn to the left after looking at my right wingman. I recovered by having my right wing pilot monitor me and talk me into believing my instruments. I recovered at approximately 1,400 ft.

This factor of head movement under instrument flight conditions and particularly during a procedural turn has been implicated in a series of fatal accidents. Head movements were related to the timing of a change in radio frequency which necessitated turning the head down and to the right in order to see the radio console. In addition, the pilot had to shift control of the stick from the right to the left hand in order to turn the radio control with the right hand. The mechanism of producing disorientation in this circumstance may be Coriolis acceleration, possibly combined with mis-
control from the head and hand movements. This results in an unusual attitude which may start a chain reaction leading to severe disorientation and a flight attitude difficult to correct. This is critical if it occurs at a low altitude. Action has been taken to correct the inadequacy of cockpit design which imposed this undesirable and hazardous requirement for head movement and control shift during critical phases of instrument flight. Following is an example of an accident of this type:

**Two Ship (F86F) IFR Training Formation Flight. Duration of Flight: 1:40. Lieut. GY, No. 2, and Capt. FY, Flight Leader.**—Mission included combat formation practice, exercise of combined fighter net, ADF letdown with GCA pickup and low approach to be accomplished by Lieut. GY. Capt. FY was then to resume lead when first approach was completed and fly a closed-pattern GCA ending in a full-stop landing. Weather 900 broken, 1,700 overcast, 4 miles visibility with ground fog.

Fligt proceeded as briefed. Leveled off at 21,000 ft. after training exercise and with Lieut. GY in lead started letdown. Letdown normal, heading 020 degrees, dive brakes out, airspeed 300 knots, 78% rpm. At 12,500 ft. the descending penetration turn was started, approach control advised, and contact made with GCA. Clouds entered at 6,500 ft. while in penetration turn. Flight rolled out on in-bound heading 240 degrees at 3,000 ft., retracting speed brakes. Shortly after level off Capt. FY experienced compression stall and tailpipe over temperature, could only get 75% power. Called Lieut. GY, who was in lead, to reduce his power. This was done. Normal GCA control continued, with Lieut. GY acknowledging normally. When 10 miles out and still at 3,000 ft. a correction from 230 to 240 degrees was given just before switching over to new channel for GCA final control. Both aircraft had gear down for landing. Lieut. GY acknowledged change to 240 degrees but no longer communicated and gave no communication over the final control channel whatever. Capt. FY was having increasing difficulty and declared an emergency and advised Lieut. GY that he was going straight in for full stop and for Lieut. GY to execute emergency procedure (climb straight ahead to 3,500 ft. and re-home on beacon). Lieut. GY did not acknowledge this transmission; Capt. FY continued inbound, unable to hold altitude (was dangerously low) and broke out of overcast near airbase. Executed emergency VFR approach and landed. He had lost sight of Lieut. GY just before final GCA control switch. A witness on ground observed Lieut. GY's aircraft break out of overcast in an inverted position with nose down 20 degrees at 900-ft. altitude. Gears down and dive brakes extended. Estimated speed of 200 knots. The aircraft rolled out of inverted position to left but "dished out" into a diving attitude of 55 degrees. In roll-out aircraft lost 500 to 600 ft., airspeed built up, power was applied, and nose rose in pull-out. Aircraft mushed in descending flight and struck ground in 10-to-15-degree nose-high attitude with wings wobbling as in a high-speed stall. Aircraft exploded and disintegrated.

The near recovery of the pilot after emerging from the cloud indicates that he was in full control of his faculties once he was able to reorient himself by contact flying. However, his altitude was too low to permit recovery from his unusual attitude in a high-performance aircraft.

**Disorientation During Transition Training.**—Some of the most serious disorientation experiences occur during early transition training in jet aircraft. Many of these pilots are unable to describe exactly how or why the disorientation occurred; this may be a reflection of inexperience resulting in more complex disorientation reactions involving interplay of the labyrinth, other proprioceptors, and central integrative functions, possibly with an overlay of mental anxiety. Some examples of this follow:

**Pilot A. Total Hours: 2,500. Jet Hours: 400. Early Jet Transition. T33.**—I was in a hooded flight in a T33 and had an episode of severe confusion resulting in a tendency to roll over on my back. I couldn't overcome this tendency and had to turn the controls over to the pilot in the front cockpit.

**Pilot A. Total Hours: 500. Jet Hours: 300. Early Jet Transition. T33.**—On my first weather flight in a T33, I was flying no. 2 on a penetration turn. I had a feeling of being upside down and pulling toward the ground. We were making a turn to the right—about 30-degree bank—and I looked away from the lead aircraft to the altimeter. I then felt very disoriented. Fortunately we shortly broke out of the overcast and I recovered normal sensations on contact.

**Pilot D. Total Hours: 650. Jet Hours: 200. Early Jet Training. T33.**—My most acute incident occurred in a four-ship formation in a T33, near Incirlik, Turkey, where we had been in a training mission. I was in a four-ship formation on a letdown in weather. I was in no. 2 position and had great difficulty in staying in formation. I felt that we were doing a formation slow roll. The members of this flight had no previous experience in weather formation flying and this first practice session on letdowns resulted in vertigo of all pilots in the formation. The formation broke up and one pilot crashed fatally.

**Disorientation due to Transition of Frame of Reference.**—Inexperience is not a criterion for disorientation susceptibility. Serious disorientation incidents occur among our most experienced pilots; however, they are usually able to recover provided sufficient time is available. It is apparent that the flight condition most liable to produce disorientation in experienced pilots is weather formation flying. The time required to transition from one frame of reference (lead aircraft) to another (instruments) is a critical factor in this instance which may determine recovery or nonrecovery. Some examples of this type of disorientation follow:

**Pilot M. Total Hours: 2,600. Jet Hours: 1,780. Recent Incident. F86.**—Flying wing in formation flight day weather, IFR letdown. During penetration we made a teardrop turn and I felt that the aircraft was upside down and lost control of the aircraft, broke formation, and went into a spin. I did an instrument recovery in the overcast. Recently while flying wing I felt I was in a turn to the right during a left turn. It was very difficult to control but I maintained formation. You have to relax and cross-check your own instruments. I never have any trouble on the gauges alone.

**Pilot J. Total Hours: 1,800. Jet Hours: 900. Time Not Recorded. F86.**—I became disoriented while descending through clouds in formation. I was on the wing and had to
break formation. I lost control of the aircraft during transition to instruments and went into a split S. I pulled 8g's and the altimeter read 200 ft. just before I blacked out in the pull-up.

Pilot I. Total hours: 450. Jet hours: 150. Time not recorded. Aircraft type not indicated—I have frequent vertigo. The worst experience occurred in a day formation flight when we unexpectedly ran into marginal weather with poor visibility. We were at low altitude and very erratic flight occurred and I nearly spun in. A four-ship formation behind our flight crashed into a mountain. My difficulty probably resulted from trying to fly both VFR and IFR in IFR conditions.

Pilot AH. Experience not recorded. Recent. F-86.—In transitioning from wing to the gauges I am frequently completely confused and have great difficulty in focusing on the instruments. One time I lost 10,000 ft. while transitioning from formation to instruments.

Pilot AI. Total hours: 540. Jet hours: 340. Recent incident. F-86.—Most recent case of vertigo was last month in formation flight in weather. It resulted from day fighting over an overcast and I went into overcast in a stalled condition. I had great difficulty transitioning to my instruments. I was able to get partially on the instruments to the extent of turning on the slave gyro and radio compass, but I realized the unusual attitude too late and didn't recover on instruments. I broke out in a vertical dive and fortunately had enough altitude to recover contact.

Disorientation due to Kinesthetic Feed-back.—While it has been stated that the labyrinthine system is primarily responsible for illusions of attitude and motion, the possible reinforcing or confounding role of other proprioceptors cannot be disregarded. Proof of this component is demonstrated in the following example, which is indicative of the possible disorienting influence of kinesthetic feed-back:

Pilot BQ. Total hours: 1,100. Jet hours: 850. Recent incident. F-86F.—I was in a day weather formation flying wing. During the flight I had sensations of being in turns and steep climbs when straight and level. One of the most confusing sensations on this flight resulted when I closed the speed brakes without retrimming. As a result of a lot of stick pressure I had a sensation of pulling up into a climb. I realized I hadn't trimmed and when I did the odd sensation of a climb disappeared.

Disorientation due to Vegetative Effects of Vestibular Stimulation.—Most experienced pilots are acclimated or habituated to the vegetative effects of vestibular stimulation and do not frequently mention symptoms relating to such effects. These symptoms are very common in early training and probably do occur among inexperienced pilots on occasion and more frequently than admitted. An example of an occurrence of this type in an experienced jet pilot follows:

Pilot BN. Total hours: 1,250. Jet hours: 820. Recent. F-86D.—Flying single ship in day weather. Clouds were in layers with approximately 6,000 ft. between layers. In breaking out between layers I became disoriented, with a sensation of skidding and not flying straight and level. The effect was nauseating. After making a climbing 180-degree turn to the left I had a sensation of skid to the right which lasted one and a half minutes.

It is quite possible that some of the central vegetative and emotional effects of disorientation may be of outstanding importance with respect to incapacitation of the pilot both physiologically and psychologically. For example, many cases of bizarre reactions occur in flight involving such symptoms as weakness, dizziness, visual symptoms, and clouding of consciousness. These reactions are sometimes associated with air-to-air gunnery training missions and with flying in severe weather.

It is known that labyrinthine stimulation can produce hyperventilation reactions and vasodepressor responses which may possibly incapacitate the pilot, particularly when positive g forces are superimposed. Further, severe mental stress is frequently produced by the flight condition associated with disorientation as well as by the psychological conflicts of disorientation itself. This combined stress may cause acute anxiety reactions which adversely affect judgment and performance. For example, a recent accident occurred in which severe disorientation was responsible for the pilot's misreading of his altimeter with an error of 10,000 ft. Believing that he had insufficient altitude for recovery, the pilot ejected from the aircraft. When he emerged from the clouds in his parachute he was still 6,000 ft. above the terrain. Other errors under similar circumstances can readily result in inappropriate procedures which may end fatally.

Frequency of Disorientation Experiences

From the foregoing discussion it is apparent that spatial disorientation can present a real problem even among experienced pilots. One may wonder about the frequency of serious disorientation experiences among pilots and the general attitude of experienced pilots regarding "pilot's vertigo" as a significant problem in operational flying. A recent study in which 685 pilots from operational units were surveyed by questionnaire and interview revealed that spatial disorientation occurs at one time or another among all pilots. While the incidence of disorientation appears to be highest among student pilots during training, many experienced pilots have stated that their first encounter with a serious disorientation incident occurred after entering operational flying. The apparent reason for this is that many pilots entering operational units for the first time are not fully prepared for operational flying conditions imposed by all-weather combat requirements.

Of the 685 pilots studied, 508 indicated mild "vertigo" experiences not interfering with pilot effectiveness, 145 indicated moderate vertigo experiences which adversely affected control of the aircraft, and 32 indicated serious vertigo experiences which resulted in loss of control of the aircraft and severe mental stress. Severe vertigo...
experiences were approximately five times more frequent among jet pilots than among non-jet pilots.

When pilots were permitted to record their experiences without reference to specific types of spatial disorientation it was found that almost 100% of recorded disorientation incidents were of the "attitude and motion" type. Visual illusions, autokinesis, geographical disorientation, and hypnogenic states were rarely recorded. It was found that most pilots feel that day weather formation flying is the flight condition most likely to produce serious disorientation.

Role of Pilot Experience and Other Factors

In general, it is the feeling of most operational pilots that spatial disorientation is not a serious problem and that proper instrument flight training and adequate practice will permit them to cope with almost any eventuality. This may be true in essence, but it is difficult to determine when instrument flight training has afforded all of the necessary training for all pilots and for all conditions of flight. It is also difficult to determine how much practice, under what conditions, is adequate. One suspects that part of the complacency regarding this problem stems, to some degree, from the "it can't happen to me" philosophy so common among those who engage in hazardous occupations. When confronted with the fact that disorientation incidents do frequently occur and that some of these apparently result in fatal accidents, the average pilot will usually shrug his shoulders in a manner of saying that these things do happen and it is usually assumed that vertigo accidents are due to inexperience or that "something went wrong."

Review of fatal vertigo accidents gives a great deal of credence to the concept that inexperience with regard to a particular aircraft and a specific flight condition is frequently involved. It is also known that some disorientation accidents occur among pilots who are exposed to a difficult flight condition after a period of little activity under instrument flight conditions, usually due to lack of opportunity. There is also the possibility that something can "go wrong," as, for example, failure of flight instruments. However, there is also the distinct possibility that even among experienced pilots and with nothing "going wrong" there may occur unusual and overwhelming vertigo experiences. These may be totally new and unexpected and cannot be adequately dealt with under existing instrument and cockpit design limitations when combined with the pilot-performance demands of present high-performance aircraft. The accidents which occur after radio channel changes, involving head movements and the Coriolis effect, probably fall into this category. Also, accidents following a transition from wing formation reference to instrument reference under severe weather conditions appear to belong to this group. A related situation exists when a pilot attempts to derive his orientation cues from two frames of reference simultaneously. Additional factors which may be involved in vertigo accidents include the possibilities of poor physical and mental status of the pilot, hypoxia, hyperventilation, effects of toxic agents, hypoglycemia, and fatigue.

Role of Sensitivity of Labyrinthine System

Many attempts have been made to determine whether some inherent characteristic of the individual is responsible for his susceptibility or non-susceptibility to spatial disorientation. Most of these attempts have concentrated on studies of the sensitivity of the labyrinthine system.

In the study cited above, 30 pilots not susceptible to vertigo and 30 susceptible pilots were selected at random on a basis of recorded vertigo experiences. These two groups and a group of controls were subjected to a series of modified Bárány tests, including a Coriolis acceleration test, in order to determine relative susceptibility to labyrinthine stimulation. It was determined that no significant correlation exists between labyrinthine sensitivity as determined by after-nystagmus time and susceptibility to spatial disorientation as determined in the questionnaire and interview survey. More recent work indicates that more refined techniques of cupulometry may reveal significant differences between the groups studied.

Some significance may be attached to the fact that the autonomic effects, including fall in blood pressure, pallor, sweating, and nausea, produced by these labyrinth sensitivity studies were more severe and more frequent in the susceptible than in the nonsusceptible group. Apparently there is better central acclimatization to the effects of labyrinthine stimulation in some individuals than in others. This could be an important factor in pilot selection; however, there is no valid evidence at present which would indicate a means of developing a reliable selection procedure for the separation of persons susceptible to vertigo from those not susceptible.

Comment

The ability to maintain spatial orientation in flight under conditions which tend to promote disorientation is an acquired characteristic. Indoc¬trination, training, and practice are, therefore, basic requirements which cannot be circumvented or shortchanged.

Pilot indoctrination regarding the mechanisms by which spatial disorientation occurs is usually considered adequate in existing programs, and little difficulty is experienced in convincing the pilot that labyrinthine and other proprioceptive sensations are totally unreliable. All pilots, at the conscious level, fully accept the concept that vision is the
only sense which can be relied upon regardless of the frame of reference, be it the earth, another aircraft, or flight instruments. They know that it is normal to have false sensations which must be ignored. In spite of this generally accepted concept, severe disorientation and resulting accidents continue to occur. It is possible that all pilots are not as completely convinced of the unreliability of labyrinthine sensations as they indicate. It has been noted that after the demonstration of motion-reversal sensations on the Bárány chair for the first time, experienced pilots frequently express amazement. Perhaps there is an indication for a more forceful and comprehensive indoctrination effort.

With regard to training and practice, it is highly probable that existing programs do not meet the requirement of assuring that all pilots receive all of the necessary training and practice required individually to assure peak proficiency in precision instrument flying. It is not suggested that this ideal can be attained; however, there is the probability that training and flying proficiency programs may not have kept pace with the sometimes staggering human performance requirements imposed by the operation of extremely high performance aircraft under adverse weather and complex tactical flight conditions.

Finally, there remains the question of whether existing flight-instrument design and cockpit layout adequately support the pilot in the performance of his task. A modern, single-place aircraft may contain as many as 200 dials, switches, and controls. During instrument flight several instruments must be consulted and discrete data must be repeatedly correlated through a cross-checking and scanning technique. This information must be centrally integrated and utilized in making appropriate motor responses. These perceptual, integrative, and motor functions are encumbered by the critically compressed time factor of high-performance flight combined with multiple in-flight stresses. It is therefore highly probable that the saturation point of the pilot's mental faculties is frequently exceeded. This may result in rejection of the instrument information and make the pilot more susceptible to disorienting sensations. There is little doubt that improved presentation of flight data for the pilot will become a more pressing requirement with the increasing progress being made in stepping up the performance of both civilian and military aircraft.

It is obvious that the problem of spatial disorientation is a complex one and touches upon numerous facets of human functions, aircraft design, and flight operations. Since the basic factor involved in the production of disorientation is a normal physiological response to the unavoidable accelerations of flight there is little one can do to eliminate the cause. It is therefore essential to consider all associated factors relating to the problem and exert increased effort to deal appropriately with all those which contribute to the establishment of spatial disorientation as a hazard of flight. Increased effort is particularly indicated in the areas of pilot indoctrination, training, and proficiency flying as well as in flight-instrument design and cockpit standardization. More vigorous application of close aircrew surveillance by the flight surgeon to assure maximum mental and physical fitness for flight among all pilots is essential. If this increase in effort prevents one fatal crash due to spatial disorientation, and there is little doubt that it will, then the cost of such effort will have been paid many times over.

Summary

Spatial disorientation is a significant flight safety problem. It can occur in any pilot, regardless of experience level. It results primarily from the effects of false sensations mediated through various components of man's proprioceptive system. The false sensations most frequently producing spatial disorientation are the illusions of attitude and motion primarily produced by stimulation of the nonauditory labyrinth by the various accelerations of flight. Little correlation exists between the sensitivity of the nonauditory labyrinth (Bárány test) and susceptibility or nonsusceptibility to spatial disorientation. Many factors impinge upon the central core of spatial disorientation which are of great significance in establishing this condition as a hazard to flight. There is need for increased effort in certain fields to reduce the importance of spatial disorientation as a flying safety problem.

References