Chapter 4

EFFECTS OF ACCELERATIVE FORCES

Flight, unnatural endeavor that it is, imposes its greatest effects upon the body through the accelerative forces applied during the course of aerial maneuvering. There is no human limitation to speed in straight and level flights, only to the changes in velocity or direction. A thorough understanding of accelerative forces and their relation to the human body in flight is fundamental to the practice of aerospace medicine. The effects of accelerative forces regarding equilibrium, spatial orientation, airsickness, and G tolerance will be discussed in this chapter.

BASIC PRINCIPLES OF AIRCRAFT MOTION

All flying is based upon one or more fundamental maneuvers of flight. With certain exceptions, all these maneuvers involve movements about different axes of the aircraft. There are three axes about which an aircraft will rotate, and three flight controls which may be used to control this rotation. The axes are the *lateral, vertical,* and *longitudinal;* the flight controls are the *elevators, rudder,* and *ailerons.*

Lateral Axis. An imaginary line which runs from wing tip to wing tip through the center of gravity, perpendicular to the longitudinal and vertical axes. Rotation about this axis (*pitch*) is controlled by the *elevators.* The elevators are the movable horizontal surfaces on the tail of the aircraft controlled by forward or backward pressure on the stick. In straight-and-level flight, when forward pressure is applied to the stick, the nose moves down; when back pressure is applied to the stick, the nose moves up.

Vertical Axis. An imaginary line which runs through the center of gravity, perpendicular to the lateral and longitudinal axes. Rotation about this axis (*yaw*) is controlled by the *rudder.* When pressure is applied to the right rudder, the nose will move to the right. When pressure is applied to the left rudder, the nose will move to the left.

Longitudinal Axis. An imaginary line which runs through the center of gravity from nose to tail. It is perpendicular to the lateral and vertical axes. Rotation about this axis (*roll*) is controlled by the *ailerons.* The ailerons are the movable panels on the outer trailing edge of the wings which are controlled by side pressure on the stick. Rotation about the longitudinal axis is caused by the lift differential created as aileron surfaces are moved out of the streamlined position. The wing with the raised aileron goes down because of decreased lift, and the wing with the lowered aileron goes up because of its increased lift. The effect of moving either aileron is greatly increased by the simultaneous and opposite movement of the aileron on the other wing. Moving the aileron control stick toward a wing raises that aileron surface, causing the wing to go down and the aircraft to roll in that direction.

The amount of pressure exerted on a control surface is governed by the airspeed and degree that the surface is moved out of its streamlined position. At higher airspeeds, small movements of the controls result in more abrupt changes in aircraft attitude than at lower airspeeds.

In addition to the above-mentioned rotations about the three aircraft axes, certain other aircraft motions are frequently encountered. "Bumping," or rapid vertical movements are encountered in turbulent air. "Corkscrewing," or oscillating movements

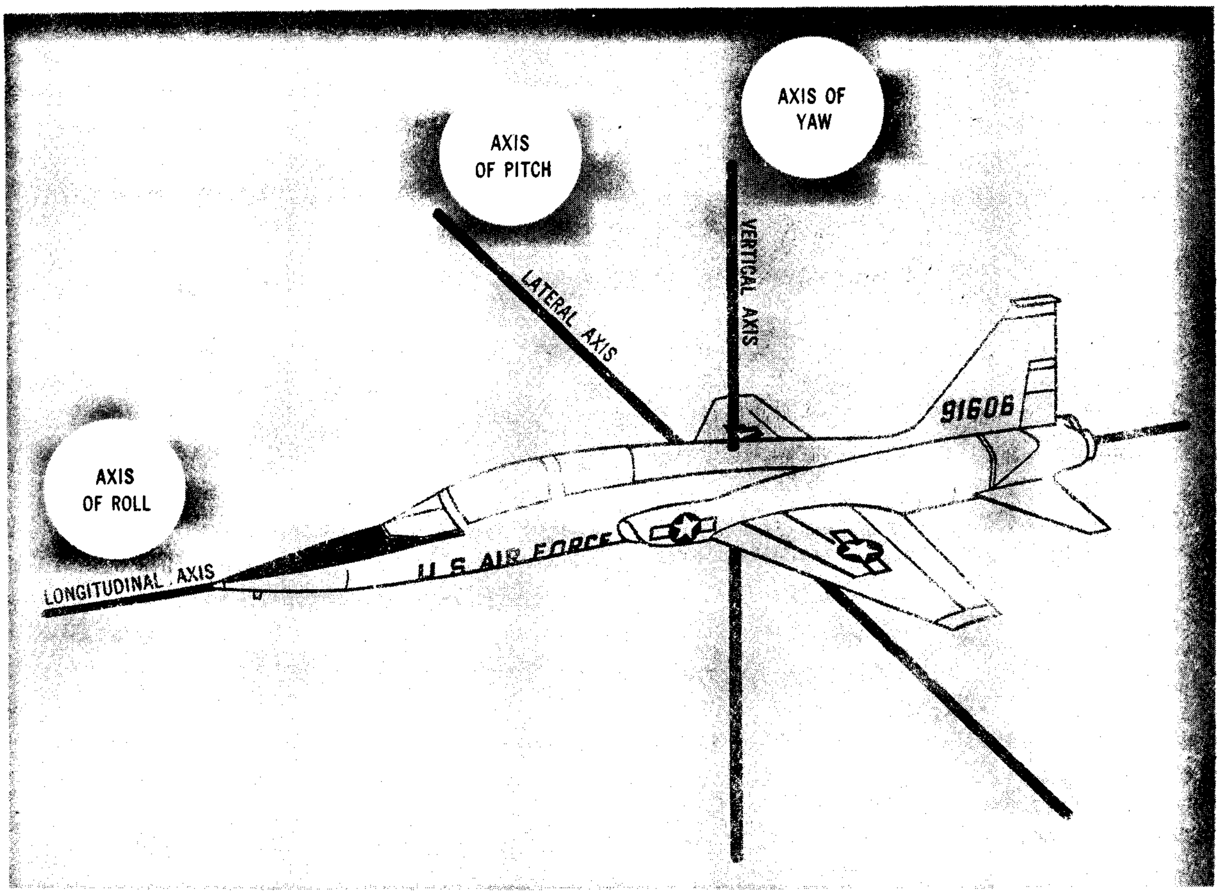


Figure 4–1. Axes of the Aircraft.

of the tail may be observed in larger aircraft, and any combination of yawing, pitching, and rolling may be observed.

Any change in aircraft attitude involves an acceleration, or change in velocity, of one sort or another. This may be a straight *linear acceleration*, or it may be a *radial* or *angular acceleration*. Regardless of the type, it has its effect upon the body.

ACCELERATIVE FORCES AS APPLIED TO AVIATION

Newton's Laws of Motion

Almost everything known about motion goes back to basic concepts put forth by Sir Isaac Newton. In 1687 he expressed three simple laws which explain the nature of the different kinds of motion and the forces causing them. These laws, known as Newton's Laws of Motion are:

Newton's first law, which is the Law of Inertia.

Newton's second law, which is the Law of Acceleration.

Newton's third law, which is the Law of Action and Reaction.

Inertia. Newton's Law of Inertia states: *a body at rest tends to remain at rest; and a body in motion tends to remain moving at the same speed and in the same direction.* In other words, nothing in nature starts or stops moving of its own volition. It requires an outside force to prevent or bring about this motion. Once a pilot climbs into an aircraft, starts the engine and takes off, inertia tends to keep the aircraft moving, subject to the various forces acting on it. These forces may add to the aircraft's motion, slow its motion, or change the direction of its motion.

The pilot of the aircraft also has inertia. When he pulls out of a steep dive, his body tends to continue in the path of the dive, and as he pulls the aircraft up, inertia presses him harder against the seat.

Acceleration. Newton's second law deals with the force involved in overcoming inertia. This force is called acceleration and is defined as change of velocity per unit of time. It covers changing direction and changing speed, including starting from rest (acceleration) and stopping (deceleration). Newton's second law states: *When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force.* This may be expressed mathematically by the equation: $a = \frac{F}{M}$ or $F = Ma$, where F stands for the number of pounds of applied force, M for the mass, and a for the acceleration in feet/sec^2. *Acceleration* has already been defined as change in velocity per unit of time. *Force* is considered to be any push or pull that tends to produce or prevent motion.

Mass is the amount of material in a body, but it cannot be measured by weight alone.

Weight varies from place to place and from altitude to altitude, depending upon the attraction of gravity. Mass is a constant quantity. It is established by the relationship between the weight of a body at a particular place and the acceleration due to gravity at that point. Weight, therefore, is purely a relative measure. It depends upon the force with which the pull of gravity can overcome the inertia of a body.

Action and Reaction. Newton's third law of motion states: *for every action there is an equal and opposite reaction.* This is best illustrated by the recoil of a rifle when the charge is fired. This principle is best known in modern aviation as it applies to jet propulsion. As the combustible vapors are burned in the jet turbine, there is rapid expulsion of the hot gases from the tailpipe. As the equal and opposite reaction, the aircraft is propelled forward.

G Forces

The most commonly known acceleration is the acceleration of falling bodies due to the force of gravity. This acceleration is 32.2 feet/sec^2 and the force producing it is called 1G. Therefore, an acceleration of 640 feet/sec^2 is 20 Gs, since 640 feet/sec^2 is an acceleration twenty times as great as the acceleration gravity. Force and acceleration are proportional ($F = Ma$) and a force which produces an acceleration of 640 feet/sec^2 is twenty times as great as the force of gravity.

Types of Acceleration

Acceleration has been defined as the rate of change in velocity in terms of G units. Let us now consider some aspects of acceleration as they apply to problems of flight. The following relationship, which involves both speed and direction, is fundamental to an understanding of how G forces are developed during flight. Acceleration varies directly with the square of the airspeed and inversely with the radius of the turn.

$a = V^2/r$ where:

V = airspeed and r = radius of turn

For example, when the airspeed is doubled, Gs increase four times. The types of acceleration encountered in flight are as follows:

Linear acceleration: This is produced by the change in the speed of an object moving in a straight line. An aircraft flying along a straight path and then increasing its speed (*e.g.* from 200 to 300 mph) is producing linear acceleration. Linear accelerations are also experienced in crash landings, catapult takeoffs, parachute openings, and landing shocks. The amount of Gs applied during linear acceleration may be calculated as follows:

$$\text{Linear G} = \frac{V_2^2 - V_1^2}{32 \times 2d}$$

where: V_1 = Initial speed in feet/sec.
V_2 = Final speed in feet/sec.
d = distance over which the object accelerates in feet.

It is evident from this equation that deceleration (going from a higher to a lower speed) will give a negative number and that acceleration (where V_2 is greater than V_1) results in a positive value. This equation may therefore be used in calculating the magnitude of force produced by both acceleration and deceleration.

Radial acceleration: Any change in direction while moving at constant speed produces radial acceleration. *Examples* of this type of acceleration are going around a curve in an automobile, pulling out of a dive or doing a loop in an aircraft. Radial G may be calculated as follows:

$$\text{Radial G} = \frac{V^2}{32 \times r}$$

where: V = Speed in feet/sec.
r = radius of the turn in feet

Angular acceleration: This occurs when a change in speed and a change in direction occur simultaneously. A good example would be an aircraft in a tight spin. So much force may be encountered in this maneuver that it may be difficult or impossible for the pilot to get out of his aircraft. Angular acceleration may be calculated by using both of the above formulae and adding the results of each to get the number of angular Gs.

Factors Influencing the Effects of Acceleration

It should be remembered that there is no difference in the physical or physiological effects of linear, radial, or angular acceleration *as long as the qualities of G are the same.* The important qualities of G forces are:

a. The degree (intensity) of the force,
b. The time (duration) of application,
c. The rate of application,
d. The area and site over which the force is applied (*i.e.* to the body), and
e. The direction of the accelerative force with respect to the long axis of the body.

In general, the greater the intensity, the more severe the effects of accelerative forces. However, intensity alone is not the only factor. A flier undergoing 12 G in a tight turn would be rendered unconscious in two seconds. Yet, a person can undergo 12 to 15 G by jumping off a table 4 feet high with no harm at all. The difference between these two examples is in the duration that the force is applied. For accelerative forces of equal magnitude, the effects are proportional to the time of application. High G forces for extremely short periods can be tolerated, and low G forces for longer periods.

The rate of onset of accelerative forces plays a part in the effects experienced. Generally, the higher the rate of application, the more severe the effect. This is best illustrated in aircraft accidents where the aircraft is decelerated over a distance as in wheels-up landings. In these cases, the accelerative forces are exerted at a rather slow rate according to the formula:

$$g = 0.034 \times \frac{(\text{mph})^2}{s}$$

where: mph is speed in miles per hour, and
s is the stopping distance in feet.

This may be compared to an aircraft that impacts vertically—*i.e.,* the stopping distance is considerably shortened. In the latter case, the rate of application of accelerative forces is many times higher.

The greater the area of the body over which a given force is distributed, the *less* harmful are the effects. In addition, the site on the body over which a force is applied is important when considering accelerative effects. It is obvious that a given force or blow to the head can be much more serious than the same force applied to some other part of the body.

Finally, the direction that a prolonged accelerative force acts on the body determines what physiological effects will occur. At the present time, prolonged accelerations during aircraft flights are caused mainly by radial acceleration. The physiological effects are the result of the centrifugal force and the increased weight of the body and its component parts.

Direction of G Force Action

As stated previously, the type of acceleration is not the important physiological factor. The direction in which the G force is applied to the body, however, does play an

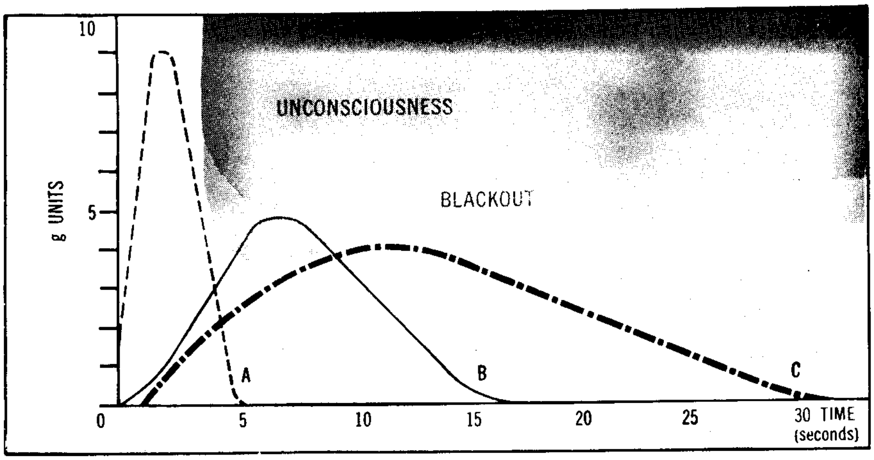


Figure 4–2. Relationship of Positive G Tolerance to Duration of G Forces.

important role in determining man's tolerance to the force. The concepts of linear, radial and angular accelerations are important in determining how G forces are produced during flight, and the equations given permit calculation of the magnitude of the force exerted. The direction in which these forces are applied to the body are of prime interest since they will reveal much as to the way in which the body is affected. The following classification is based on the position of the body in relation to the force applied to it.

Positive G. G force is positive when it acts in a head-to-foot direction, as when we stand erect. When positive G forces are experienced, a temporary displacement of blood occurs caudally, which may lead to blackout and unconsciousness.

Negative G. When G forces act from foot-to-head they are termed negative G. *For example,* a man standing on his head experiences one negative G. Negative G forces produce a temporary displacement of the blood in the head and neck resulting in "red out" and unconsciousness.

Transverse G. G forces acting on the body in the prone or supine position are termed transverse Gs. Man is most tolerant to this type of G force and can withstand transverse Gs of higher magnitude and for a longer duration than either positive or negative G. During transverse G, the blood in the body is temporarily displaced transversely, across the longitudinal axis of the body. Respiratory activity becomes labored and unconsciousness may ensue from prolonged exposure.

It is important to get the concepts of positive, negative, and transverse G clearly differentiated because their effects on the human body are quite different. As an example of this difference, the average pilot can withstand from 4 to 6 *positive* Gs for 3 to 5 seconds without blacking out. With a force of only 3 *negative* Gs, he is in danger of "red out" and unconsciousness. He can stand as much as 15 *transverse* Gs with only moderate discomfort.

EFFECTS OF G FORCES

Effects of Positive G

Positive G forces have three main areas in which they produce their effect: the *body* as a whole, the *viscera,* and the *cardiovascular* system. The latter is the most important and will be discussed in detail.

a. *Body:* During a maneuver which produces positive Gs, the weight of the body is increased in direct proportion to the magnitude of the force. For example, a 200-pound man weighs 800 pounds during a 4 G maneuver. Normal activities are grossly curtailed and the flier is pushed down into his seat. His arms and legs feel leaden, his cheeks

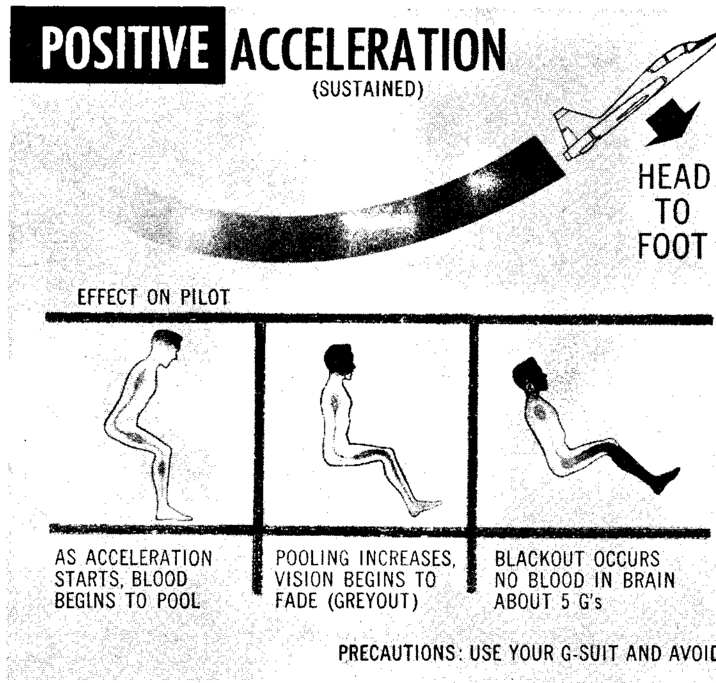


Figure 4–3.

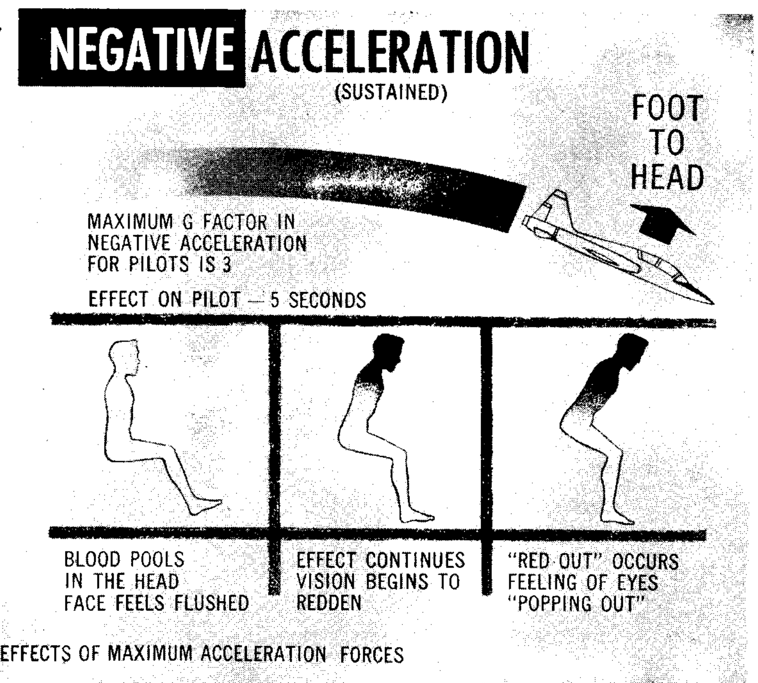


Figure 4–4.

sag and he becomes incapable of free body movement. In fact, 2 to 3 Gs (either positive, negative, or transverse) is the limit permitting escape from a spinning aircraft. This is one of the reasons why the pilot ejection seat was adopted by the Air Force.

b. *Viscera:* During a positive G maneuver, the viscera are pushed caudally. The increased weight of the viscera pulls the diaphragm down, increasing the relaxed thoracic volume and disturbing the mechanics of respiration.

c. *Cardiovascular System:* Man is so constructed that when he is seated, the heart lies approximately at the point of junction of the upper and middle thirds of a long, cylindrical body. The head, that structure most sensitive to reduction in blood pressure, is at one end of this cylinder, approximately 30 cm. from the heart. When a force of 5 positive Gs is exerted on the body a standing blood column of 30 cm. exerts a pressure of 120 mm Hg upon its base. As this is equal to the normal arterial systolic pressure, it will exactly balance out the arterial pressure and cause blood perfusion of the brain to cease. This results in unconsciousness.

At about 4 G, blackout occurs. It will be remembered that static intraocular pressure is about 20 mm Hg. When positive G forces are sufficient to reduce the systolic arterial pressure in the head to 20 mm Hg, intraocular pressures cause collapse of the retinal arteries. The retina ceases to function as the blood supply fails, and vision narrows from the periphery centrally. This usually occurs at about 4 to 4.5 Gs. When the force reaches approximately 5 Gs, cerebral blood flow is stopped and unconsciousness ensues. Hence, the sequence of events following exposure to positive Gs is dimming of vision, blackout, and then unconsciousness.

The effects just described are usually progressive. For example, in relaxed subjects in the human centrifuge, the first symptoms due to positive G force occur at 3.5 to 4.0 Gs, and involve a graying or dimming of the visual fields. At slightly higher accelerations, 4.0 to 4.5 Gs, blackout occurs and the individual can no longer see, although he remains conscious. At this point, the retinal arteries have collapsed while there is still some blood flow through the cerebral vessels. At 4.5 to 5.0 Gs unconsciousness occurs.

It was formerly believed that pooling of the blood in the lower part of the body, as occurs during positive G maneuvers, and decreased venous return to the heart were primarily responsible for the loss of consciousness and blackout. Experimental work in recent years has shown that the pooling mechanism takes an appreciable time to come into operation and that unconsciousness occurs more rapidly than can be accounted for on the basis of decreased venous return.

It is now believed that the primary cause of blackout and unconsciousness, occuring in less than 10 seconds, is the increased weight of the blood, as described above. Although decreased venous return does occur, and is an important factor, it probably takes 15 seconds or more for it to produce its effects on the body. It is probable that blackout produced by relatively low G forces—*e.g.*, 3 or 3.5 Gs after 15 seconds, is due to pooling.

Effects of Negative G

Negative acceleration, force applied from foot-to-head, will result in an increased arterial pressure at the head level. The pressure within the veins outside of the cranial cavity becomes precipitously high, which may be sufficient to rupture the thin-walled venules. Intracranial venous pressure rises, but is counterbalanced by a concomitant rise in intracranial cerebrospinal fluid pressure, so there is little actual danger of intracranial hemorrhage. Hemorrhages within the eye present the primary source of damage from negative Gs. Negative Gs cause distention of the jugular veins and veins of the sinuses and conjunctivi. There is a sharp rise in both arterial and venous pressures at the head level.

Sudden acceleration producing a force of 3 negative Gs is considered the limit of human tolerance. When such a force is applied, venous pressures of the order of 100 mm Hg develop, leading to small conjunctival bleed-

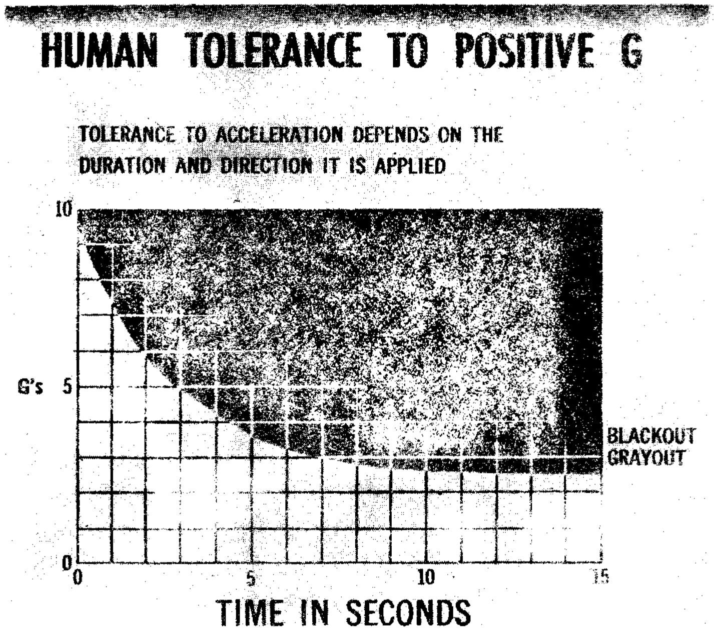


Figure 4-5. Human Tolerance to Positive Acceleration.

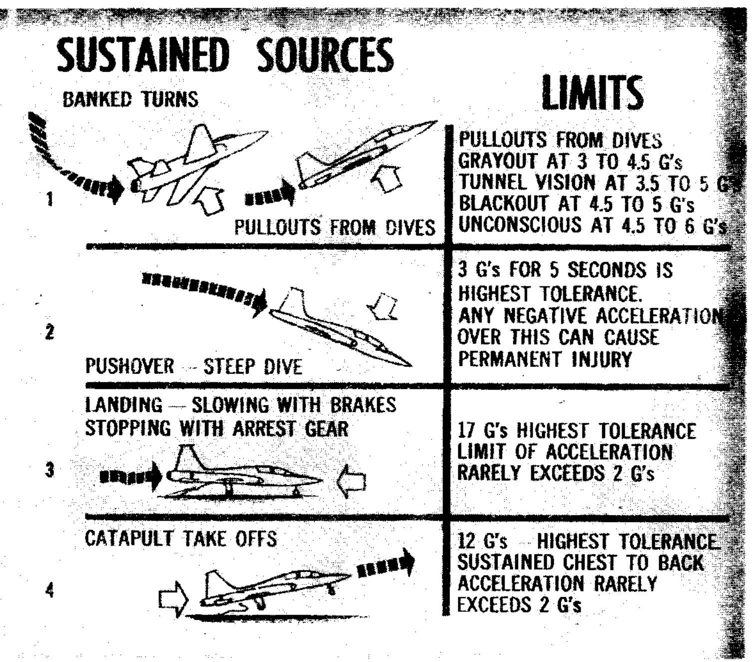


Figure 4-6. Limits of Sustained Gs.

ing areas and marked discomfort in the head region. On the other hand, the pressure-protected cerebral vessels, enclosed in the skull and bathed in cerebrospinal fluid, show no deviation from their normal caliber. Thus, there is no danger of cerebral vascular damage as long as the skull remains intact.

During negative G maneuvers it has been reported that vision may "red out." Although no cases of this condition have occurred during experimental work, it is possible that in aircraft, vision may be obscured by the gravitation of the lower eyelid over the cornea. The muscles in the lower eyelid are relatively weak due to the tendency of gravity to normally hold it down. The covering of the eyes by a red curtain (since the vessels of the eyelid are engorged) may be responsible for the reports of red out during negative Gs.

Gravitation in the foot-to-head direction will also lead to eventual circulatory distress if sufficiently prolonged. Pooling of blood occurs in the head and neck regions because of the increased weight of the blood. This leads to a transudation of fluid from the blood into the tissue spaces of the head and neck. Also, return of blood to the heart becomes inadequate due to the loss of effective blood volume. As a consequence there is a stagnation of blood in the head and neck, and the cerebral arteriovenous pressure differential becomes inadequate to sustain consciousness. Actually, negative Gs do not present much of a problem in military flying because it is an uncomfortable experience for pilots and they tend to avoid it.

Effects of Transverse G

Since the force of transverse G interferes very little with the flow of blood, man is much more tolerant of transverse G than either positive or negative G. Extreme values of transverse G (12 to 15 Gs) acting for a relatively long period of time may cause some displacement of organs or a shift in position of the heart and thereby interfere with respiration. Chest pain and ventricular arrhythmias have been experienced by human subjects when exposed to 15 Gs for 5 seconds. Surface petechial hemorrhages have also been seen. These were probably caused by the forceful pooling of blood in the dependent half of the body.

G TOLERANCE

As has been indicated, tolerance to G loads is relatively constant from person to person. Within the human body, only by positioning to shorten the heart-to-head distance, or by increasing systolic blood pressure can tolerance to G loads be increased appreciably. Advantage of these principles may be taken by leaning forward to reduce the length of the blood column to the head, and by tensing all skeletal muscles to activate pressure reflexes and thus increase blood pressure. This latter procedure, called the M-1 maneuver, also serves to inhibit venous pooling of blood in the lower extremities.

Care should be taken to keep the glottis open during the M-1 maneuver as closure of the glottis frequently involves performance of the Valsalva maneuver, which is to be avoided during positive G loads. In the Valsalva maneuver, the lungs are filled with air and blood is expressed from the pulmonary vasculature. The increased intrathoracic pressure generated inhibits venous return to the right side of the heart, and thus cardiac output diminishes and sudden unconsciousness may result. Under increased positive G loads, the Valsalva maneuver decreases, rather than increases, G tolerance.

Excitement, or emotional stimulation such as rage or fear, may increase blood pressure and pulse rate and thus G tolerance. This is extremely variable, however, and the amount of benefit derived may be outweighed by other factors.

Physical fitness plays an important part in G tolerance. Poor muscle tone, fatigue, lack of sleep, hypoxia, hypoglycemia, illness, and excessive use of alcohol or tobacco all decrease tolerance to positive accelerations.

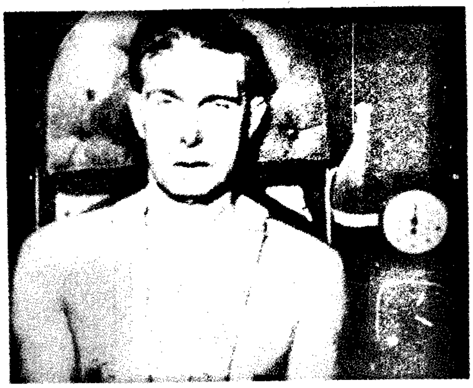
Experience is also important in G tolerance. The experienced pilot has developed compensatory "reflexes" such as tensing his muscles as Gs are "pulled." He has learned to anticipate and recognize when his G limits are approaching and to react accordingly. He

At 2.2 G subject experiences no reduction in visual acuity, little discomfort.

At 3 G strain is evident in facial distortion; dimming of vision is noticed.

At 4 G facial distortion is marked; peripheral vision, lost. Subject is fighting G.

At 5 G peripheral vision, lost, central vision greys; he shouts to maintain vision.



At 6 G subject is fully conscious but blacked out. Average tolerance is 5 G.

Figure 4-7. Effects of Positive G.

knows what he can do to most effectively combat the effects of positive G forces, whether it be to lean forward or tense his muscles.

Devices to Protect Against G Forces

The two means currently employed to combat positive G forces are the M–1 maneuver and the anti-G suit.

M–1 Maneuver

Straining maneuvers are adopted by all experienced fighter pilots. Their exact techniques vary and they can be adjusted to suit the individual. M–1 maneuver is effective in raising G tolerance by approximately 1 or 1.5 Gs. It is accomplished as follows: the trunk is bent forward at the hips, thus giving some degree of postural protection—*i.e.*, the level of the head is lowered in relation to the heart, thereby facilitating the flow of blood from the heart to the neck and head. At the same time, the abdominal and chest muscles are contracted and the breath is slowly expelled. Respiratory cycles are repeated every 5 to 10 seconds. Arm and leg muscles are tensed simultaneously. This maneuver is fatiguing, and as the duration of acceleration increases it becomes more and more difficult to maintain the effort.

Anti-G Suits

External counter-pressure below the level of the heart has proved of great value in combat aircraft for increasing human tolerance to the application of added G forces. The anti-G suit has been developed toward this end. The original concept was to balance, by counter-pressure, the hydrostatic forces that result from gravitation. This concept was later expanded to provide for a garment which would compress the arteries to some extent, thereby increasing arterial pressure.

The single pressure and air bladder suits now generally employed, accomplish both these requirements to a large extent in that they help prevent venous pooling and, by increasing peripheral resistance by mechanical constriction, they increase arterial pressure at the heart and head levels. This is accomplished, for the most part, by the large ab-

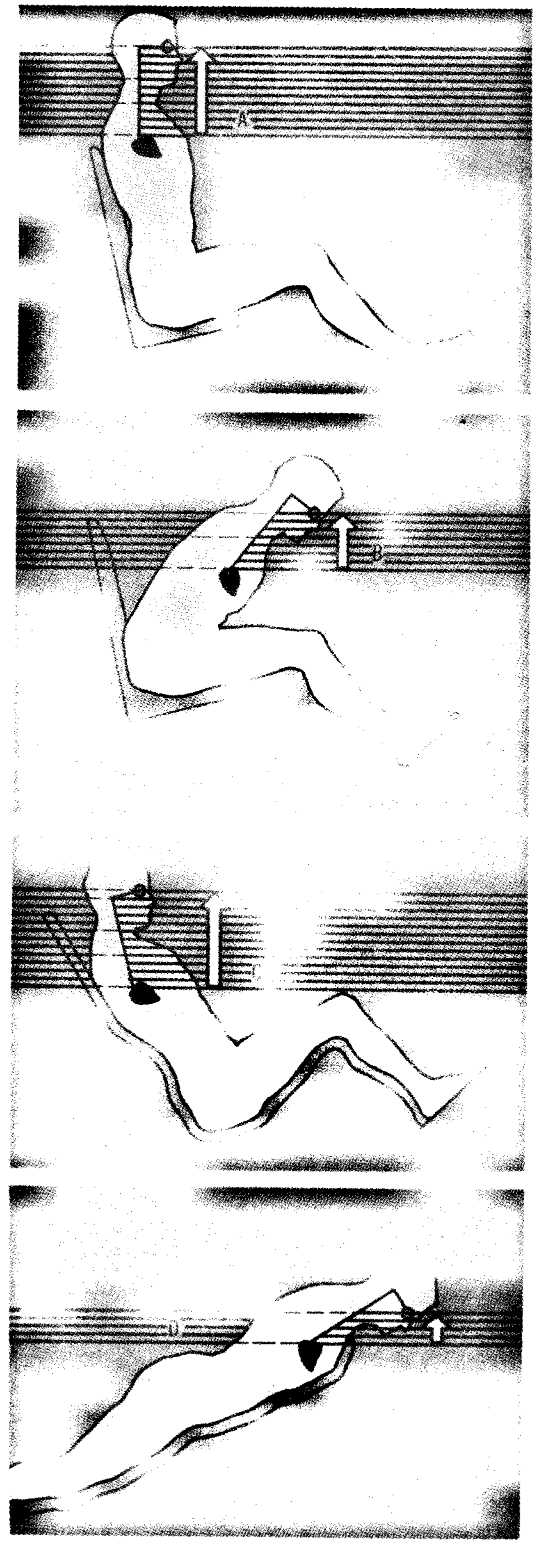


Figure 4–8. Effect of Position in Heart to Head Distance.

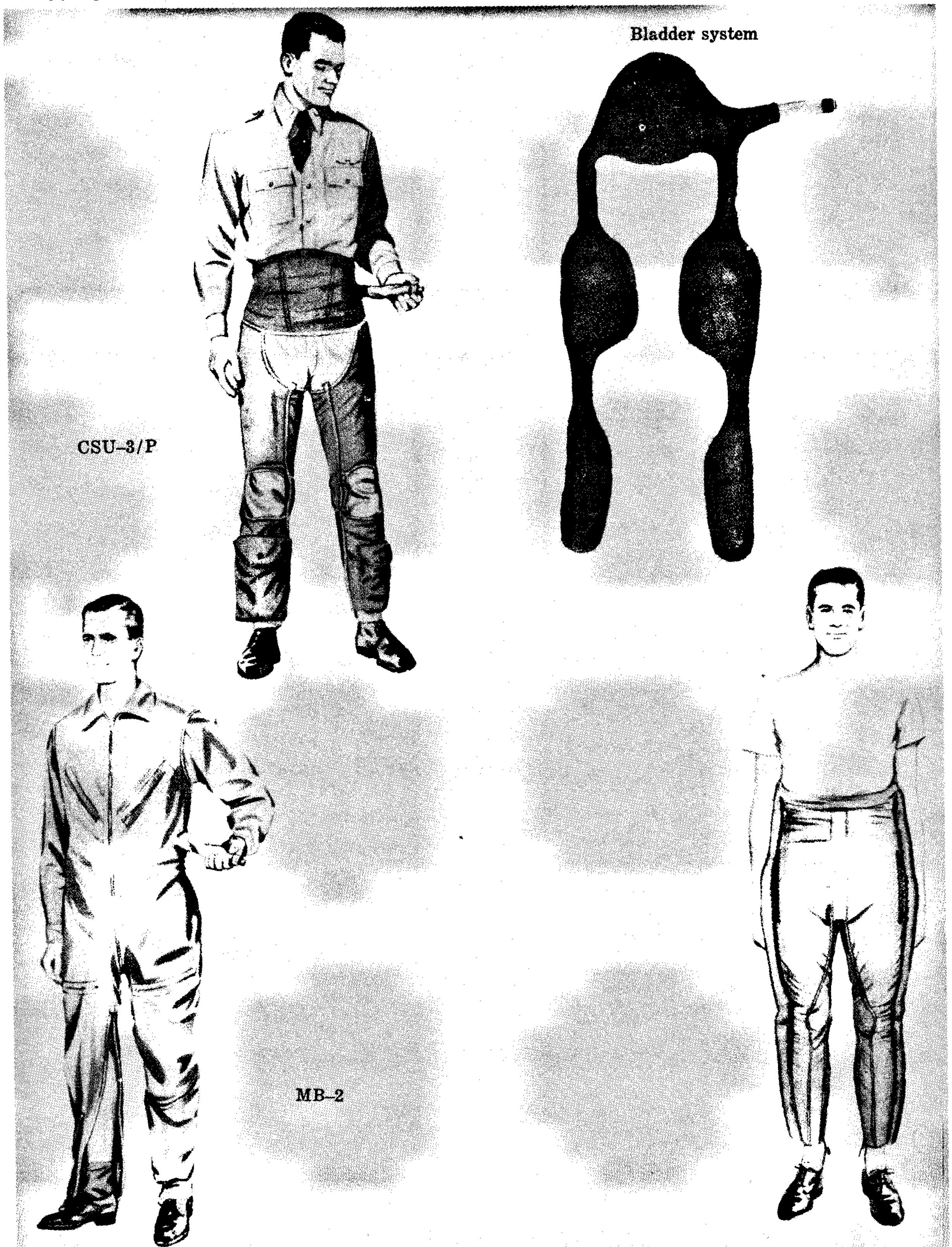


Figure 4-9. Anti-G Suits.

dominal bladder which squeezes the viscera when it is inflated during a G maneuver, and drives blood up into the thorax. In addition, it raises the diaphragm and significantly decreases the distance from the heart to the head.

The current standard anti-G suit, Type MB-2 consists of a single pneumatic bladder system sewn within a flying suit. This device raises tolerance to accelerative forces by approximately 2 Gs, and thus gives on the average, about the same protection against positive G forces as does the M-1 maneuver. It eliminates the need to tense or strain without removing the advantage gained from the maneuver, for the M-1 may still be employed to gain further protection if so desired.

Figure 4-9 shows the pneumatic anti-G suits and their bladder system. The CSU-3/P suit consists of the minimum essentials necessary for applying the pressure of the one-piece bladder system to the abdomen and major muscles of the legs and is worn over flying clothing.

Inflation of the anti-G suit in jet aircraft is accomplished by a line connected to the power plant. Air from the compressor is metered to the suit by a special valve which starts inflation only when the acceleration exceeds 2 Gs. The pressure then increases in proportion to the acceleration. In this way the pilot may relax and the suit compresses his legs and abdomen, thereby replacing the muscular effort of the M-1 maneuver. The pressure is relatively comfortable and can be maintained indefinitely.

It should be emphasized that an anti-G suit does not raise human tolerance to acceleration above the stress limits of the aircraft. It merely matches the man to the aircraft. In those aircraft that are stressed to 5 Gs or less, fliers do not require anti-G suits unless prolonged maneuvers of 0.5 to 1 minute are contemplated. In the standard fighter aircraft anti-G suits are desirable because volunteer straining is fatiguing, distracting, and unreliable.

SENSORY RESPONSES TO ACCELERATIVE FORCES

Sensory Modalities

The ability of a person to appreciate the attitude of his aircraft in reference to the earth's surface is known as aerial equilibration, or spatial orientation.

Equilibration of body posture at rest and in motion requires constant muscular activity. It is controlled by the central nervous system which, in turn, must rely upon the sensory modalities that guide it. Man maintains his equilibrium through the proper interpretation of the sensation arising in the eyes, the vestibular apparatus, and the various proprioceptors, such as nerve endings in muscles, joints, tendons, skin, and viscera.

The eyes are the most important sense organ for flight orientation. While flying in clear weather, aerial equilibrium may be maintained by direct observation of the ground and horizon.

The vestibular apparatus is part of the inner ear, and is located in the temporal bone. It consists of three fluid-filled, semicircular canals connected to an irregular saclike organ known as the utricle. The canals are arranged at right angles to each other in the vertical, horizontal, and transverse planes. Angular acceleration of the head results in movement of the fluid in a pair of canals or combination of canals in the plane or planes of movement.

For example, nodding results in movement of the fluid in the semicircular canals. Vertical change affects the vertical canals; banking affects the transverse canals; and turning affects the horizontal canals. In the ampullae, or dilated ends of the canals, hairlike projections are located which extend from the wall into the fluid in the canals. Because of the inertia of the fluid, it tends to lag behind the movements of the head much as fluid in a glass at first will remain stationary if the glass is rotated quickly. This movement of the fluid deforms the hairlike projections and initiates neural impulses that are interpreted as movements. If the

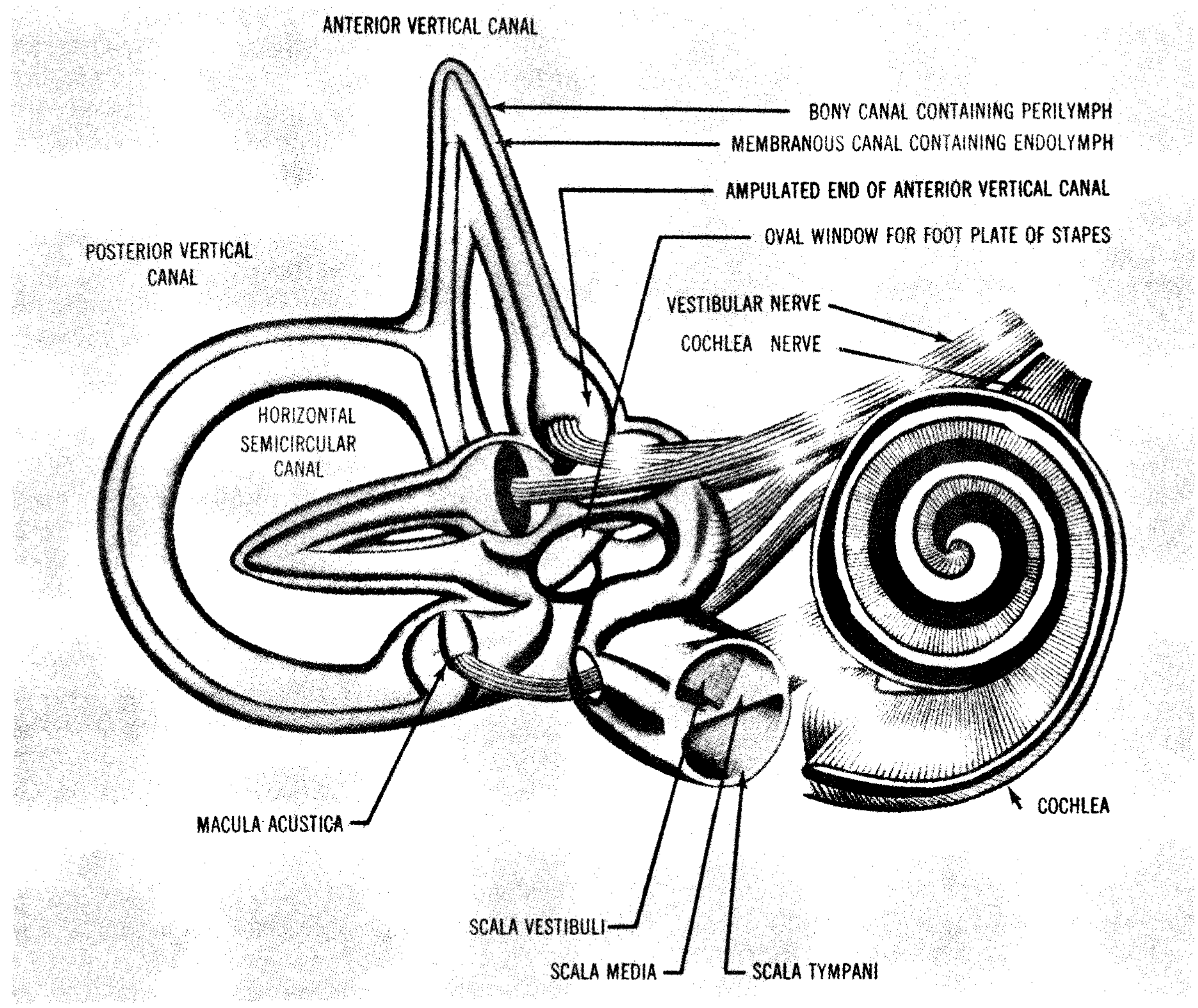


Figure 4–10. The Inner Ear.

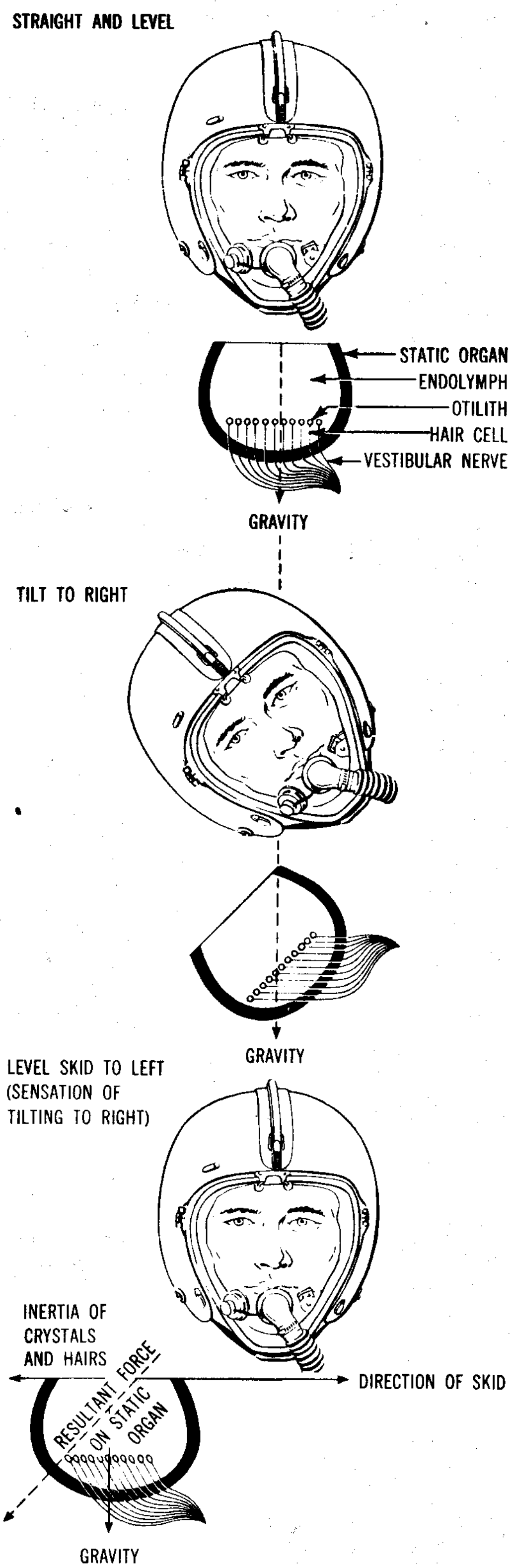
glass is stopped, the water will continue to rotate.

A similar condition exists in the semicircular canals. If prolonged rotation of the head ceases abruptly, the fluid will continue to move in the canals. This continuance of motion produces the same sensation as turning the head in the direction opposite to the original motion. Hence, there is a sensation of turning in the opposite direction. The utricle, or so-called static organ to which the semicircular canals are connected, contains numerous hair-like nerve endings to which are affixed tiny crystals or otoliths.

The sensations arising in the utricle, together with sensations from proprioceptors in the neck and shoulders, are interpreted and recognized by the individual at various positions of the motionless head. In the upright position the hair-like endings in the utricle are not deformed. However, if the head is tilted the nerve endings are stimulated by the deformation resulting from a change in the direction in which the force of gravity is acting upon the hair cells.

The proprioceptors are responsible for the sensations that arise from pressure on or from movement of a joint or muscle. This "deep sensibility" enables man to point, sit down, or walk with his eyes closed. It is responsible for the knowledge of where an extremity is in space.

Perhaps the greatest departure from the reflex equilibration of terrestrial man is en-



Head Position.

countered in flying. Here is an almost total departure from terrestrial stimuli; physical contact is limited to the aircraft itself. The aircraft operates without reference to the direction or force of gravity. To the beginner, muscle sensibility has no relationship to the attitude and orientation of the aircraft. Since vision is removed from customary close points of reference, much training is required before accurate aerial orientation is established.

Stimuli serving equilibrium are further modified by the kinetic factors of flight; accelerations and decelerations are quite marked. Rotation through varying degrees of arcs and at varying rates, as well as in different patterns, is encountered. With rotation, centrifugal force profoundly modifies the direction of linear acceleration, and may add to or subtract from the force of gravity.

Equilibration as it is known on the ground must be transferred to equilibration of aerial flight. The maintenance of aerial equilibrium, then, is dependent upon the attitude of the aircraft rather than the body position of the pilot.

Vestibular Responses

The acceleration necessary to stimulate the vestibular apparatus is said to range from 2 to 20 cm per second per second linearly, 2° per second per second angularly, and from 4 to 12 cm per second per second vertically. Motions with less acceleration than these minimal limits will not be detected by the end organ. Changes in direction of motion of aircraft must have comparable accelerations to be detected by the pilot. If the angular acceleration of an aircraft about any of its axes is less than 2° per second per second, the vestibular apparatus will not be stimulated and the sensation of turning will not occur.

Measurements of the capacity of the vestibular apparatus to detect elevations and declinations were made many years ago at the Air Service Medical Research Laboratory. Blindfolded normal individuals were found to detect approximately 24° elevation and 10.6° declination. Experienced fliers demonstrated considerably more sensitivity, detecting 7° elevation and 4° declination. Measurements by other research groups show similar results for tilting movements as well as for elevation and declination.

Perhaps the strongest and most uncontrollable vertiginous response of the vestibular apparatus is response to Coriolis acceleration. This occurs when one rotation is superimposed on another as when the body is in rotation with the aircraft around one axis and the head is momentarily rotated about another not parallel to it. The effect is strongest when the two axes of rotation are at right angles. Such a situation arises during a spin when the head is moved up or down, or from side to side.

The type of vertigo aroused by this maneuver may be readily demonstrated with the turning chair by the following procedure. With the head rotated back 60°, a standard turning of 5 turns in 10 seconds is carried out. In accordance with the rules of vestibular response to stimuli, the vertigo and nystagmus induced are seen to be in the plane of rotation. The subject sits calmly in the chair and feels little distress from the vertigo in the axis of rotation. The head is brought sharply forward, and a violent reflex reaction occurs, which may be described as tending to throw the subject out of the chair sideways. The superimposition of acceleration of the direction of vertigo from a horizontal to a vertical sagittal plane is described by the subject as a sudden and uncontrollable loss of equilibrium, which would be completely incapacitating in an aircraft.

Proprioception

In flying, the individual is usually seated, and the forces exerted upon him are such that, with training, he can tell many movements of the aircraft by the pressure of the seat on his body. An increase of this pressure occurs in climbing, and any maneuver that produces pressure against the seat will be interpreted as climbing. In descent he is pressed less firmly into the seat than in normal flight, and consequently any maneuver that reduces pressure on the seat will be interpreted as descending. In a slip or skid the pilot is forced sideways in his seat. Since this impression usually results from tilting, he will have the impression of tilting in the direction away from the slip or skid.

It must be understood that equilibration of man, particularly vestibular function, exists largely at the lower reflex centers of the brain stem and is adapted to terrestrial existence. There is little variation from one normal individual to the next in reflex adjustments of equilibration. Reactions to the unusual stimuli of flight, then, are generally predictable, and are subject to the processes of learning.

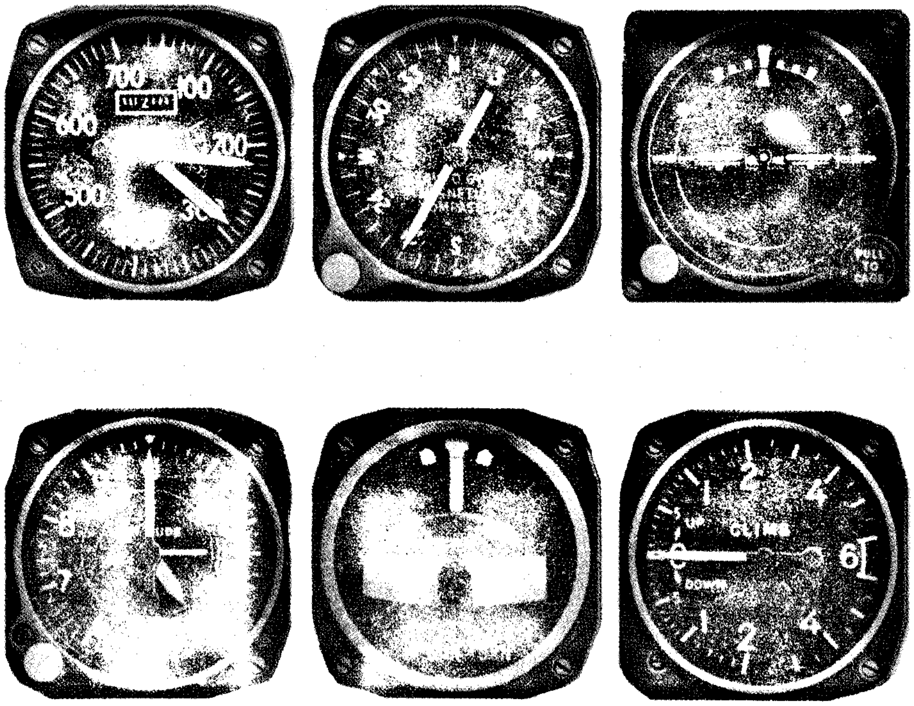
ILLUSIONS OF FLYING

Studies of the human factors limiting blind flying outline certain fairly well-defined phenomena arising under such conditions—the illusions of flying. Identification and understanding of these patterns of equilibrial incapacities under conditions of blind flying resulted in a clearer understanding of human limitations and a successful search for mechanical aid.

Optical Illusion

Probably the best known illusion of flying is experienced in flying between sloping cloud banks when the horizon is not visible. If the aircraft is oriented straight and level with respect to the earth's surface, the sensation of flying in a bank is experienced. Another illusion of vision occurs at night and is called *autokinesis*. This is a sensation that occurs when an individual stares at one light for a long period of time. Eventually the light will appear to move, although actually it does not.

The illusion may occur while flying as wing man during formation flying at night. While staring intently at this light, autokinesis may occur and the light may appear to move up or down. Sometimes this illusion may be so vivid as to lead the pilot to believe that the lead man has made a sudden bank of his aircraft when actually he is flying straight and level. It may result in his turning away from or sharply toward the lead plane with resultant disastrous effects. This illusion may be avoided by not staring continuously at the wing light of the lead plane.



PRIMARY PITCH SUPPORTING BANK SUPPORTING PITCH

Figure 4-12. Flight Instruments in Straight-and-Level Flight.

Illusion of Turning

Historically, a study of this specific illusion demonstrated the need for the development of instrument flying. It provided a most dramatic proof to the pilot of the fallibility of his own sensations, and the necessity for reliance upon instruments.

While a gradual turn may be undetected, if it is suddenly corrected, it may give the impression of turning in the opposite direction, for the fluid in the involved semicircular canals continues to move in the direction of turn once the head is restored to the original line of flight. Here again, the original gradual stimulus of turning was insufficient to cause any sensation, but with a cessation of turn there was sufficient deceleration of the fluid in the semicircular canals to give a false impression of turning in the opposite direction. The mechanism of the illusion is readily understood in terms of vestibular physiology.

For example, this illusion is greatest in the spin, for in this maneuver the rotation of the head and of the fluid in the semicircular canals is rapid. In an aircraft rotating to the right through several turns of a spin, the endolymphatic fluid obtains momentum in the direction of turning just as when the patient is spun to the right in a Barany chair. As the aircraft is brought out of the spin, the same sequence of events occurs as with physiologic testing in the Barany chair when brought to a stop after rotation.

With movement of endolymph to the right, a left nystagmus is induced, accompanied by vertigo, past-pointing, and falling tendencies to the right. Thus, the pilot coming out of a spin to the right may feel that the aircraft has resumed its spinning, this time to the left, although he is in straight and level flight. To compensate for a sense of spinning left, he adjusts the controls to the right, and again spins to the right just as a patient past-points or falls to the right after physiological testing.

The mechanism of this illusion was used by David A. Myers, a Flight Surgeon, and W. C. Ocker, a pilot, to convey the necessity for instrument flying to the Air Force.

Illusion of Tilting (the Leans). An illusion arising from another fallibility of the vestibular apparatus is a sensation of tilting felt by the pilot when his instruments indicate the wings are level. This arises from the inability to detect gradual motions. Rotation of the head must occur at a certain minimum rate in order to be detected by the semicircular canals. During instrument flight, visual reference to the instruments is largely successful in eliminating or suppressing false vestibular sensations.

The instruments, to the trained instrument pilot, replace the horizon and other reference points as a visual guide. During a period in which the eyes are occupied with scanning other instruments, or during a momentary inattention to the instrument, various rolling or pitching motions of the aircraft are prone to produce vestibular stimulation, which leaves a persistent and uncomfortable, as well as erroneous, sense of posture.

For example, if during instrument flight and while the eyes are momentarily off the instruments, the aircraft should suddenly roll sharply to the left, the vestibular senses will properly record the movement. Then, if the aircraft gradually rolls back to even keel at a rate below the threshold of the vestibular apparatus, the pilot is left with the sensation of being tipped to the left and there is no awareness of return to the vertical position. Although he maintains the aircraft in level flight in conformity to the instruments, the sensation that he and the aircraft are tipped to the left remains. To correct this feeling, the compulsion to lean to the right is almost irresistible, and may persist until the pilot breaks through the clouds and corrects his equilibrium by the more familiar horizon and other terrestrial reference points.

Leans may be produced by the opposite sequence of stimuli. In this case, the gradual roll from level position may be succeeded by a sharp correction to level flight. In a similar manner, forward or backward pitch movement of the aircraft may produce leans in these directions. Some pilots report themselves particularly susceptible to leans as they wave back and forth in standard patterns to the edge of radio beams.

Undetected Motion. A group of illusions arise from the incapacity of the vestibular apparatus to detect slight acceleration. As a consequence of the inability of the vestibular apparatus to detect these subthreshold changes in motion, a relatively high rate of turning, climbing, driving, or banking may be built up gradually without the perception of any change from straight and level flight.

Underestimating the Degree of Bank. The same incapacity of the vestibular apparatus which permits unperceived changes of motion is responsible for underestimating the degree of banking while turning during blind flight. Since the rate at which an aircraft is banked while going into a turn is ordinarily below the threshold at which such motion is detected by the vestibular apparatus, there is a tendency for the pilot to bank too steeply while turning, and to overcorrect in recovery from the turn.

Illusion of Climbing or Descending. A properly executed turn brings the vector of the forces of gravity and centrifugal force through the vertical axis of the aircraft. In the absence of visual reference, the only sensation imparted is awareness of the body being pressed more firmly into the seat. Normally, this sensation is associated with climbing, and may be falsely interpreted as such.

Following the increased pressure of the body on the seat brought about by the centrifugal force of turning, recovery from turning lightens the pressure. As a consequence, an illusion of descending is produced.

Illusion of Opposite Tilt in a Skid. In the execution of turns during blind flying, there is improperly compensated centrifugal force as a result of a skidding that presses the body away from the direction of turning. This is interpreted as a tilt in the opposite direction. In a similar manner, slipping of the aircraft as a result of too much banking presses the body into the direction of the turn.

Instrument Flight. From any analysis of human factors in maintaining equilibration in flight, it is obvious that vision is the one absolute necessity. For the student learning noninstrument flight, the horizon is the essential point of reference. It rises and falls above the nose of the plane as the pitch attitude is changed, it slants contrawise to the tilting of the plane, and it sweeps in a circular manner beyond the nose of the turning aircraft.

From the earliest days of flying it became increasingly apparent that the best pilots were unable to fly when visual reference to the surroundings were obscured. Flying under conditions of clouds, fog, dust, and darkness, which obscured visual reference to the earth, came to be termed "Blind Flying." Much effort was expended, with little gain, by each pilot to overcome the difficulties of blind flying by the improvement of personal flying ability. The answer was, of course, in the development of sensitive instruments that would accurately depict the flight condition and attitude of the aircraft. The basic instruments used for this purpose are the airspeed, rate of climb, and attitude indicators, and the rate of turn, or needle and ball instrument.

Capacity to accomplish equilibration in the air with instruments calls for special training beyond the requirements of ordinary flying. The pilot must not only familiarize himself with the commonly encountered illusions of flying, but must develop the capacity to maintain orientation on the instruments in the presence of such illusions.

SPATIAL DISORIENTATION

The problem of accidents due to spatial disorientation has been and continues to be a source of serious concern in the United States Air Force. A recent study has shown that this one factor was responsible for 14% of the fatal aircraft accidents in one of the major oversea commands of the US Air Force.

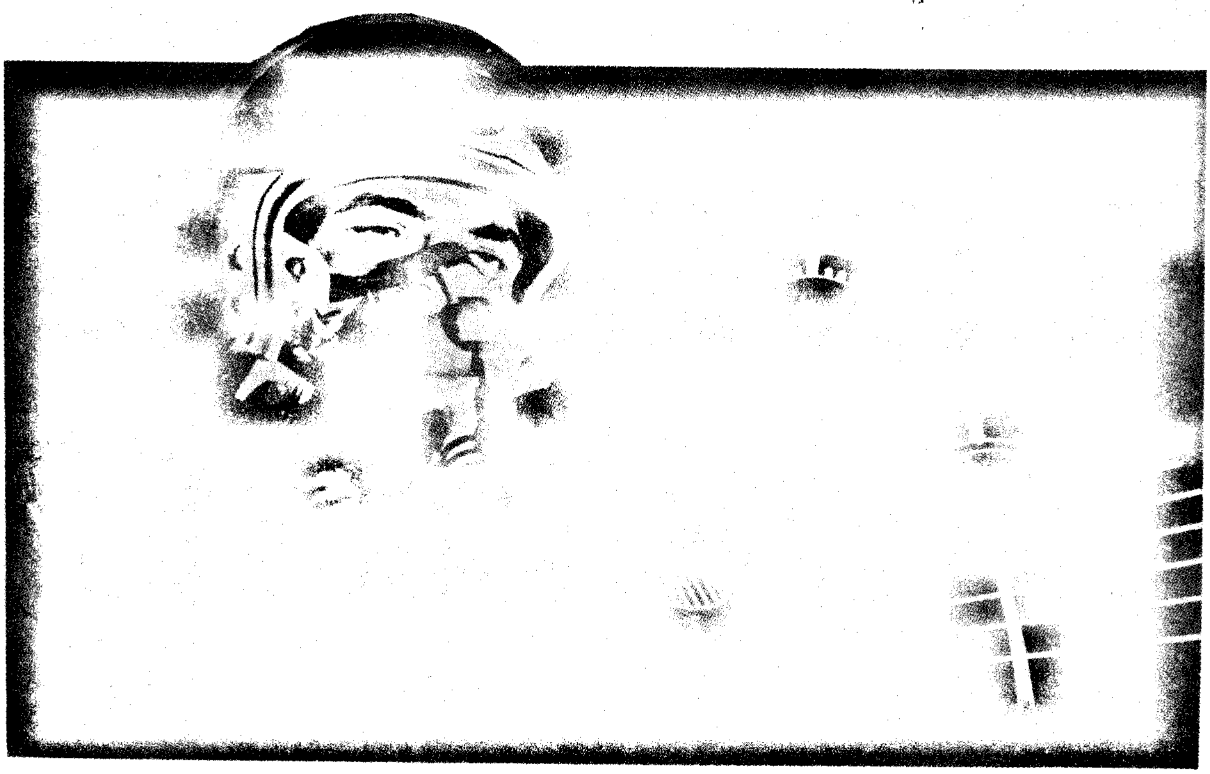


Figure 4–13. When Spatial Disorientation Occurs, Flight Should be Accomplished With Reference to Visual Interpretation of the Instruments.

The sensory aberrations producing disorientation in pilots may be divided into two categories: *visual illusion*, and *illusions of attitude and motion*. By far, the most important are illusions of attitude and motion. These are interpreted through the vestibular apparatus, primarily the semicircular canals and the otolith organs of the utricle and saccule.

As described previously, the human body is oriented in space by input from three sensory modalities; the eyes, the nonauditory labyrinth, and the proprioceptors located in muscles, tendons, joints, and viscera. In clear weather when visual, or "contact" flight conditions exist, there is little chance for disorientation to occur as the eyes act as the "major domo" for positional sensory input. During obscured flight conditions when visual sensation is restricted, the other sensory modalities play a more prominent role.

It is under such conditions—*i.e.*, weather or night flying when the horizon is not visible, that the majority of spatial disorientation incidents are reported. The reason for this is that visual sensations are almost 100% reliable, whereas labyrinthine sensations in flight are, on the contrary, almost 100% unreliable as a means of orientation in space. The perceptual confusion, resulting from increased awareness of vestibular information by the pilot, 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.

Sensations from the semicircular canals may be erroneous for two basic reasons. First, the canals are stimulated by angular acceleration which displaces the cupula. This produces a sensation of rotation only as long as the cupula is displaced. If the acceleration is constant, or is decreased, the sensation of rotation stops, or seems to reverse. At any rate, the impression the pilot receives bears little or no relation to the actual direction or magnitude 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. This produces an after-sensation of rotation after the acceleration ceases. In addition, the otolith organs produce positional cue errors because they are stimulated by both gravity and rectilinear acceleration without being able to distinguish between forces due to gravity and those caused by other accelerations.

Not only is information from the vestibular organ frequently erroneous, but it is often in conflict with information received from the proprioceptive organs. One can imagine the plight of the hapless pilot, bombarded with positional sensory information from several sources, none of which is in consonance with that from the other sources.

Disorientation occurs most frequently during obscured flight conditions, as stated previously. In addition, periods of transition training in jet-type aircraft seem to witness a higher incidence than normal. This may reflect inexperience resulting in mental anxiety and more complex reactions involving interplay of visual, labyrinthine, and proprioceptive functions. Inexperience, however, is not a constant quality associated with disorientation. Serious disorientation incidents occur among our most experienced pilots.

While the incidence of spatial 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. Jet flying does show a definite propensity to produce disorientation. Severe vertigo experiences are approximately five times more frequent among jet pilots than among nonjet pilots when balanced statistically for equal hours flown in each type aircraft.

Unfortunately, there is some apathy among pilots regarding this problem. Most have experienced disorientation to some degree and managed to overcome it uneventfully. The prevalent attitude is that proficiency in instrument flying and adequate practice will suffice to prevent any serious spatial disorientation incident. No doubt this is important, but it should be the job of every Flight Surgeon to give proper emphasis to the gravity of this problem in educational efforts directed to pilots.

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. Indoctrination, training, and practice are, therefore, basic requirements which cannot be circumvented. It should be remembered 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.

AIRSICKNESS

All who fly are susceptible to airsickness. At one time commercial flights were plagued by the specter of various passengers in assorted stages of airsickness. Now that larger, more stable aircraft, less affected by turbulent air currents are in widespread use, airsickness has become less of a problem. The pressurization systems, luxurious interiors and general increase in comfort has also helped to alleviate this problem. Nevertheless, airsickness remains the most discomforting condition facing travellers.

The usual response to repeated exposure to motion sickness-producing situations is adaptation, with reduction or disappearance of symptoms. Military fliers, particularly students in the initial phase of flight training, show a rather high incidence of persistent airsickness. These cases can be divided roughly into two classes: (1) Those with organic-contributing factors, and (2) those associated with anxiety and lack of motivation for flying.

Persons with organic abnormalities are relatively rare. They have a strong history for carsickness, seasickness, and sickness on carnival rides or other devices producing repeated abrupt accelerations of moderate magnitudes. An occasional episode of seasickness or carsickness cannot be used to identify persons who will exhibit chronic airsickness.

A hypersensitive nonauditory labyrinthine apparatus seems to be the most common organic factor. These individuals will frequently show violent reactions to labyrinthine stimulation such as that produced by the caloric test or spinning in the Barany chair. Such candidates rarely adapt to the accelerations of flying and should be considered poor prospects for pilot or navigator training.

The most frequent type of persistent airsickness in flying trainees seems to be the type that involves anxiety regarding flying, in combination with the motion produced in flight. Lack of motivation for flying enters into the picture, but usually only after a few flights. The trainee, rather than adapting to the rigors of his new environment, begins to develop a definite aversion to the sensations experienced in the course of aerial flight. Often mild maneuvers trigger an episode of violent airsickness in such persons.

Typical situations involve gentle turns, climbs, glides, or approaches to landings. These situations could hardly be constituted as maneuvers producing sickness in most individuals. In addition, these persons tend to lean away from turns, that is, maintain a posture oriented with respect to the earth's surface rather than to the aircraft, and to grasp the sides of the cockpit or the top of the instrument panel during turns or maneuvers. Fortunately, the majority of such individuals rapidly adapt to flying and began to lose their apprehension regarding flying after a few flights.

When familiarity with the sensations of the various accelerations of flight is acquired, and confidence in the aircraft and the instructor is established, airsickness usually ceases to be a problem. Furthermore, by this stage the student is doing most of the flying and is beginning to concentrate on techniques and procedures necessary to progress in the program. This distracts him from the thought of being sick and he rapidly reaches the point where airsickness is no longer a problem.

Those still having trouble after eight or ten flights probably will never adapt. Also, by this time usually one of two things has occurred. Either the student's motivation for flying has fallen so low that he really does not care whether he "makes it" or not, or he has fallen so far behind in his training that he becomes subject to elimination because of flying deficiency or failure to progress.

By understanding and diligence, the Flight Surgeon may be able to salvage a high proportion of students evidencing airsickness in the early training period stages. Psychological support, advice, and an expression of confidence in the student should be the attitude of the Flight Surgeon. He should see the student as soon as possible after each episode of airsickness, and inquire about the various maneuvers performed, the student's mental attitude toward flying, whether or not flying frightens him, and his relationship with his instructor. In addition, it might be well to contact the student's instructor and discuss the particular case with him.

In his counselling, the Flight Surgeon should emphasize that the student strap himself in the aircraft securely; that he look outside the aircraft during turns and maneuvers; that he control the aircraft as much as possible; and, that he fly straight and level for several minutes when general uneasiness occurs. In the early stages, one of the various airsickness drugs may be prescribed. If such is done, the student's instructor should be so advised, and the student should not be cleared for solo flight. Any student still experiencing airsickness should not solo, regardless of his level of flying proficiency.

If it becomes obvious a student is not responding to therapeutic measures, he must be considered for recommendation for elimination in accordance with current Air Force directives. Each case must be evaluated on an individual basis. A particularly well-motivated student with outstanding potential as an officer might be carried longer than a student who is poorly motivated and shows little prospect of ever being a successful flier.

The symptoms of airsickness are generally well known and consist of epigastric uneasiness, diaphoresis, pallor, and excessive salivation, followed by frank nausea and retching. The symptoms are relieved temporarily by gastric evacuation, but tend to recur if the flight is not terminated.

In commercial aircraft, a reclining posture with fresh or cool air directed on the face of the airsick person seems to help. Movement to a position in the cabin over the center of gravity—*i.e.*, generally the area where the wing meets the fuselage—is sometimes helpful. Moments of acceleration are less in this area, and are greatest in the tail of the aircraft. The sipping of small amounts of a carbonated beverage over cracked ice will occasionally afford some relief.

If a passenger has a tendency to get airsick, one of the antimotion sickness drugs may be prescribed. The antihistamine type agents such as dimenhydrinate 50 mgm. every four hours, cyclizine 50 mgm. three times daily, or meclizine 25 mgm. twice daily, are most frequently used. There is little to choose between the three. Dimenhydrinate is said to cause the greatest degree of drowsiness; cyclizine the least. Meclizine has the longest acting effect and may be taken only once or twice daily to maintain a therapeutic level.

If it is desired to prescribe a drug that will have a soporific effect, probably one of the proprietary drugs containing hyoscine, a belladonna alkaloid, and phenobarbital would be preferred.

With student pilots, only dimenhydrinate, cyclizine or meclizine should be prescribed. The reason for this is rather obvious. These drugs are specifically for motion sickness and the side effects are minimal. In addition, drugs containing belladonna alkaloids paralyze accommodation and impair vision in therapeutic doses. Flying-training students should not be allowed to use any antimotion sickness drug to the point of becoming dependent upon it, either physiologically or psychologically. This may be difficult at times, as most antimotion sickness drugs may be purchased across the counter without a prescription. Students having trouble with airsickness should be particularly warned about the dangers of self-medication so they will not be tempted to take antimotion sickness remedies, or other drugs, at their discretion.

This discussion has mentioned two groups of persons, namely commercial air passengers and flying-training students. One other group, less numerous than either of the above groups, but nevertheless important, should be mentioned for the sake of completeness. This group involves rated pilots that experience chronic airsickness when they transition to an aircraft considerably different from the ones they have been accustomed to flying. Usually this involves transitioning to single-engine jet aircraft when they have been flying cargo or transport-type aircraft with reciprocating engines.

These persons present complex emotional problems that manifest themselves in airsickness. Frequently these fliers have been ordered to the new-type flying somewhat against their will. Usually, they have been away from acrobatic or operational flying for many years and feel that they are "too old" for that sort of flying. Too, many are settled with families, are nearing retirement age, and are only too aware of the risks involved in jet flying where the demands upon the human operator are greatly increased. Their airsickness stems from lack of motivation for this new sort of flying, lack of confidence in their ability to attain and maintain proficiency in the aircraft, and the physical sensations of accelerations and motions that have been long since forgotten.

All this is balanced against the pressure of completing the course satisfactorily, or being grounded permanently. Most fliers in this position deny any fear of flying, but readily admit they do not like to fly the new aircraft. These cases require more time and counselling than student pilots evidencing airsickness, but the approach is still the same. Interest and understanding is paramount to the successful handling of such cases.

ABRUPT ACCELERATIONS

Whereas prolonged accelerations, such as the type described in the previous section, occur routinely during the flight of high-performance aircraft, crewmen usually encounter abrupt short-duration accelerations only under emergency conditions. The potential drastic effects of high-magnitude, abrupt accelerations, however, make a thorough understanding of the mechanics and human responses to these accelerations important. An in-flight emergency requiring the crewman to abandon the aircraft leads to his exposure to a complex sequence of accelerations. This sequence consists of:

a. The accelerations associated with the ejection of the man and the escape system to provide separation from the aircraft.

b. The subsequent deceleration as the system encounters windblast at high speeds.

c. The exposure of the crewman to a series of complex angular motions whose magnitude and duration depend on the inherent stability of the escape device and on the initial speed, altitude, and attitude of the aircraft at ejection.

d. Angular motions related to sustained spinning during free fall from high altitudes.

e. The abrupt accelerations produced by the opening of the parachute, and

f. The accelerations produced by landing with either the conventional personnel parachute, or within the confines of the newer escape capsule. Deceleration produced by crash landing is also to be considered.

The severity of the forces created in each of these stages varies with the aircraft and the initial conditions under which escape occurs. For instance, propeller-driven aircraft are not equipped with ejection systems, and bailout speeds are usually low enough so that windblast and abrupt deceleration are not problems. Survival, with or without injury, depends on the adequacy of the escape system and its personal protection devices, and on the proper use of these protective devices.

In the following sections, the abovementioned phases of the sequential accelerations encountered during escape will be treated in more detail. The first of these gives a brief review of the development of escape devices and illustrates how increased performance of aircraft has created a greater need for more sophisticated escape systems.

Development of Escape Systems

In the early part of World War II, bailouts were accomplished by using escape hatches or by climbing over the side of the cockpit. As speeds increased and uncontrolled maneuvers of the aircraft produced high G forces, it became increasingly difficult to effect a safe escape from a crippled aircraft. Aircraft in uncontrolled spins generate radial accelerations which greatly hamper the crewman's ability to leave the aircraft. Accelerations of 1½ G greatly reduce ability to leave the aircraft; it is impossible to do so with accelerations of greater than 2½ G.

The first operational ejection seat was developed and used by the Germans in the later stages of World War II. Their research in human responses to the abrupt accelerations associated with ejections, accomplished during the period from 1939 to 1945, remains classic. Further, their physical analysis of tolerable loads on the human vertebral column and subsequent definition of acceptable acceleration profiles for ejection are still used in design of escape systems today.

In 1945, shortly after the end of World War II, a US team, led by Doctor W. Randolph Lovelace, II, traveled in Germany and Sweden to gather information on ejection systems developed in those countries. The team brought back to Wright Field, Ohio, a Swedish J–21 seat and a German Heinkel He. 162 seat, along with considerable data on ejection systems. The use of this data, along with some experiments performed in this country, led to the development of the first American ejection seat. The seat and its capabilities were very similar to the German He. 162 seat.

On 17 August 1946, First Sergeant Lawrence Lambert was ejected over Wright Field, Ohio. This represented the first American live ejection from an aircraft. The first emergency ejections from US Air Force and US Navy aircraft occurred within 3 weeks of each other. On 8 August 1949, a Navy pilot successfully ejected from his flamed-out McConnell F2H–1 "Banshee" fighter. Three weeks later, on 29 August 1949, an Air Force pilot ejected from his North American F–86 "Sabrejet" safely when the aircraft went out of control.

In the 10 years following the first emergency ejection from an Air Force aircraft, there were 1,897 ejections. Of these, 1,538 (81%) were successful, that is, not fatal. Thirty-five % of the fatalities occurred as a result of the aircraft going into an uncontrollable dive. The most important factor in successful ejections has been the amount of terrain clearance available at the time of ejection. Figure 4–16, shows that, while only 12% of all ejections occur at altitudes of less than 500 feet, 55% of all ejection fatalities occur as a result of these low-altitude ejections. Figure 4–15 illustrates that 94% of all ejections occur at airspeeds under 400 knots, and 87% of all fatal ejections occur at airspeeds under 400 knots. Again, a large percentage of these fatalities are the result of low-altitude ejection. The percent of fatal ejections at speeds greater than 400 knots is approximately twice the percent of total ejections at these higher speeds. This is because of the increased probability of mechanical failure of the aircraft at higher speeds and the increased chance of uncorrectable human error. With the present operational requirements for higher speed in flight and particularly, high-speed, low-level penetrations, one expects these statistics to be more exaggerated. These operational performance requirements have led to the sophistication of ejection seats and associated equipment and to the development of escape capsules.

Ejection seats have been made more stable to better withstand the deceleration forces produced with high-speed ejections, and many systems have incorporated rocket catapults which continue to provide thrust after the system has left the aircraft. This additional thrust provides increased trajectory to improve low-level recovery capability, improves the basic stability of the escape device, and reduces the magnitude of the

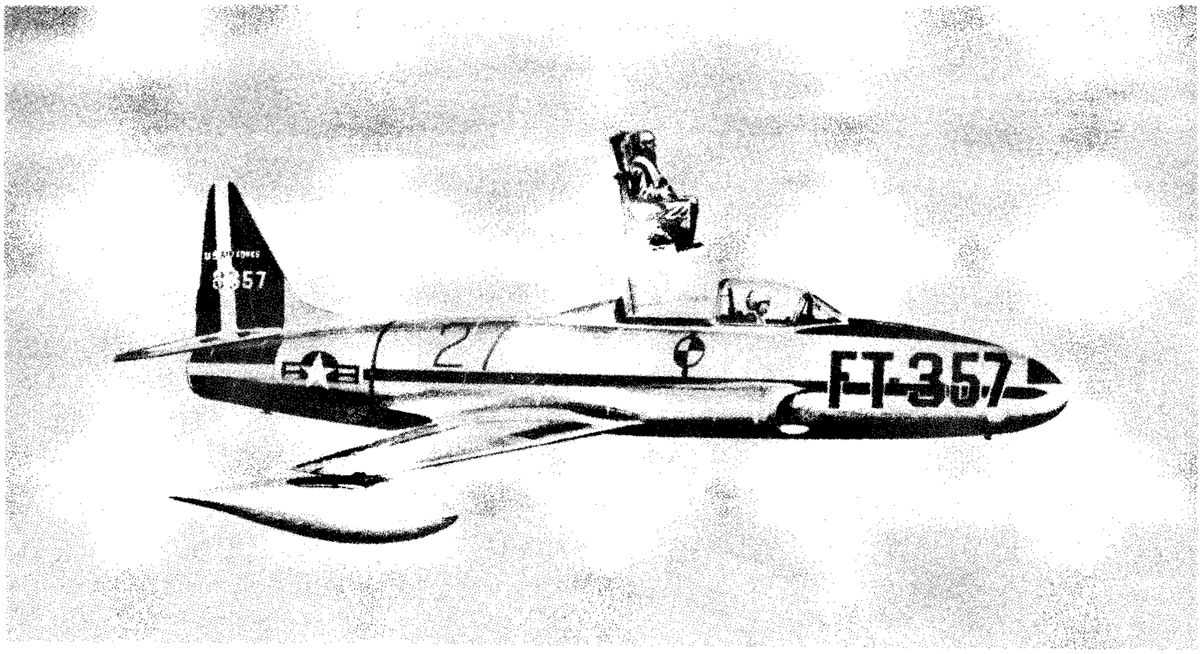
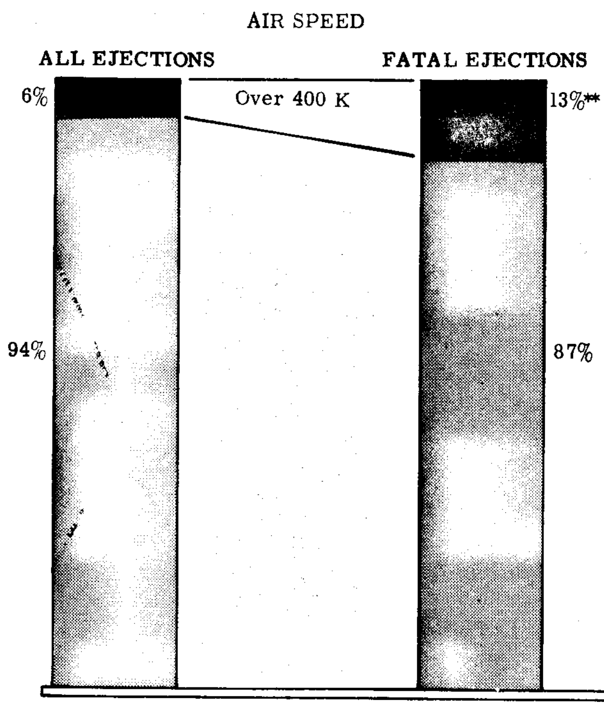
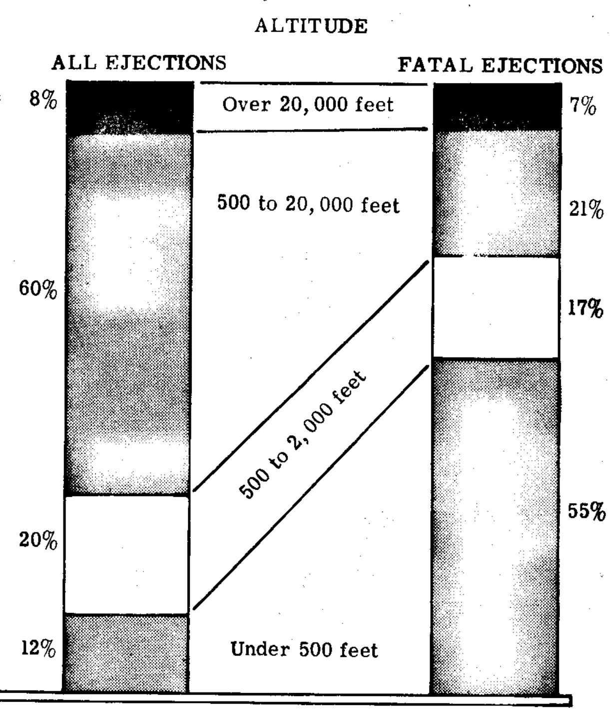


Figure 4-14. Experimental Ejection To Test the System.



After 8-year experience in the US Air Force, there were 115 ejections which resulted in 49 fatalities in which the air speed was unknown.
** Not all fatalities over 400 K were due to Q forces.

Figure 4-15. Relationship Between Air Speed and Ejection Success.



After 8-year experience in the US Air Force, there were 40 ejections with 29 fatalities in which altitude was unknown.

Figure 4-16. Relationship Between Altitude Above Terrain and Ejection Success.

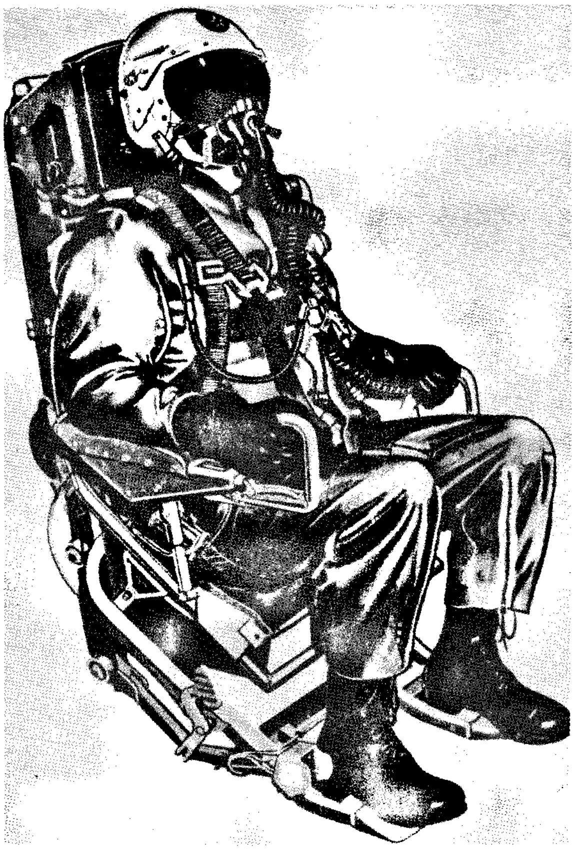


Figure 4–17. Correct Position for Ejection.

deceleration produced by wind blast. The solid propellant used in these rockets has the additional advantage of producing much more repeatable acceleration profiles than did the powder charges which were used in earlier escape systems.

The only currently operational aircraft employing escape capsules is the B–58. Capsules provide better stability during high-speed ejections, provide a substitute for the pressure suit at altitudes in excess of 50,000 feet, eliminate the problem of windblast effects on man, and provide shelter and water flotation after descent. They have, by virtue of their rockets, good low-level recovery capability. These increased benefits to the crewman make up for the increase in weight of the aircraft. The Air Force has established a design requirement for capsules in all future aircraft flying at speeds in excess of 600 knots and at altitudes greater than 50,000 feet.

In summary, as operational performance of the parent aircraft increased, the provisions for escape became more sophisticated and elaborate. With the many types of aircraft in current use today, one may encounter escape systems which vary from the personnel parachute to the completely-inclosed escape capsule. It is important for the flier to be intimately familiar with the performance and use of the particular escape system of his aircraft.

Ejection

An adequate ejection mechanism must:

a. Provide the thrust necessary to propel the occupant clear of the aircraft (particularly, the high vertical stabilizer in modern jets).

b. Give a trajectory which is adequate in very low-level ejection to permit deployment of the parachute.

c. Accomplish these requirements without producing injury to the crewman. Most escape systems employ upward ejection of the occupant; however, some aircraft utilize ejection systems which propel the man downward. The advantage of the downward ejection system is that clearance of the aircraft can be accomplished with much lower thrust; the disadvantage is that it provides poor low-level capability. The rocket catapult provides the capability to attain adequate trajectories in upward ejection without exceeding human tolerance limits by allowing longer durations of thrust. These longer durations permit lower peak accelerations.

Upward ejection systems achieve a velocity ranging between 50 and 70 feet per second in the vertical direction at the time they leave the aircraft. This velocity is attained over a distance of about 4 feet. The most efficient way to reach the desired velocity is to generate a nearly square wave acceleration profile. However, as the Germans discovered in the early 1940's, the very abrupt onsets, with the duration of acceleration and peak G required, produced a high incidence of compression fractures of the lower thoracic and upper lumbar vertebrae. The generally accepted human limits for accelera-

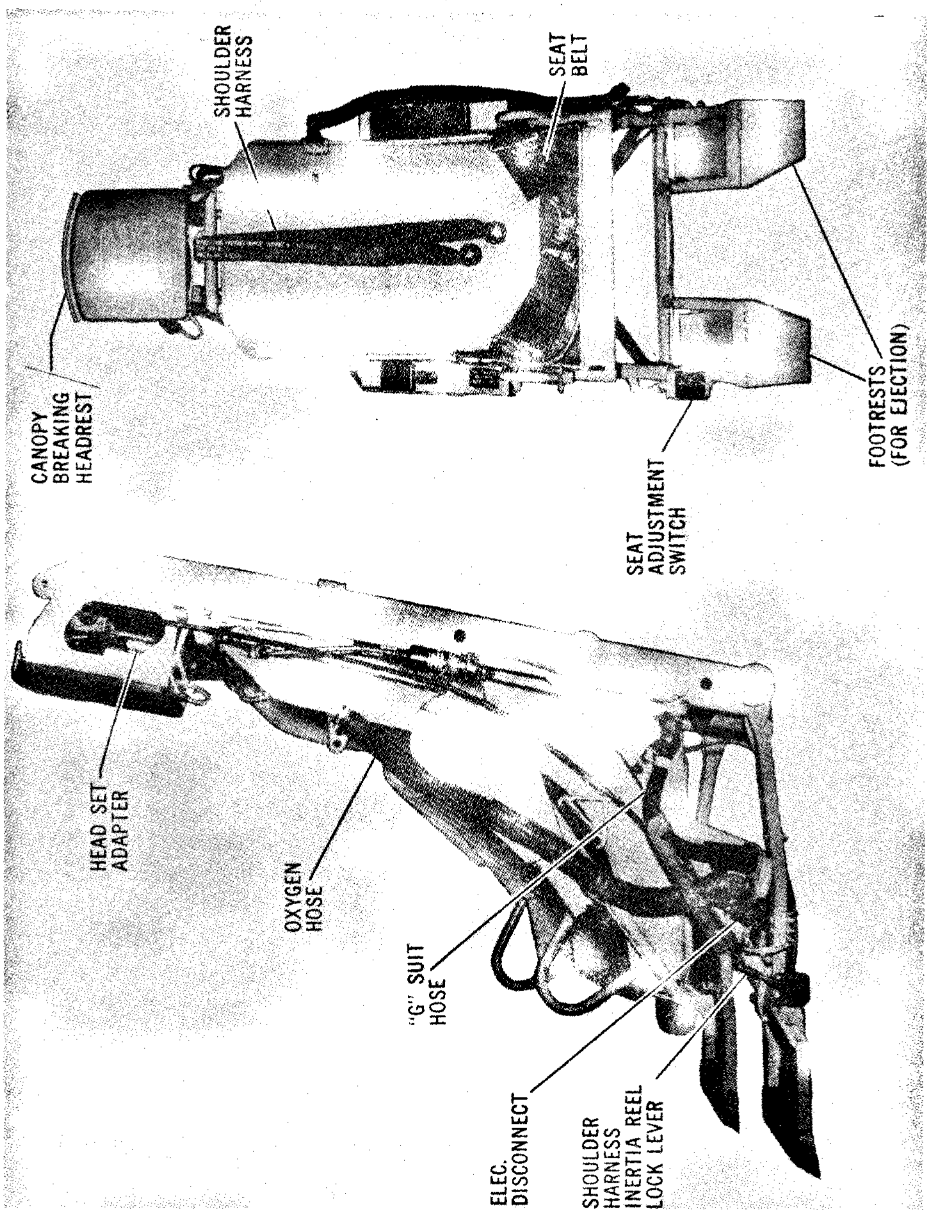


Figure 4–18. Ejection Seat.

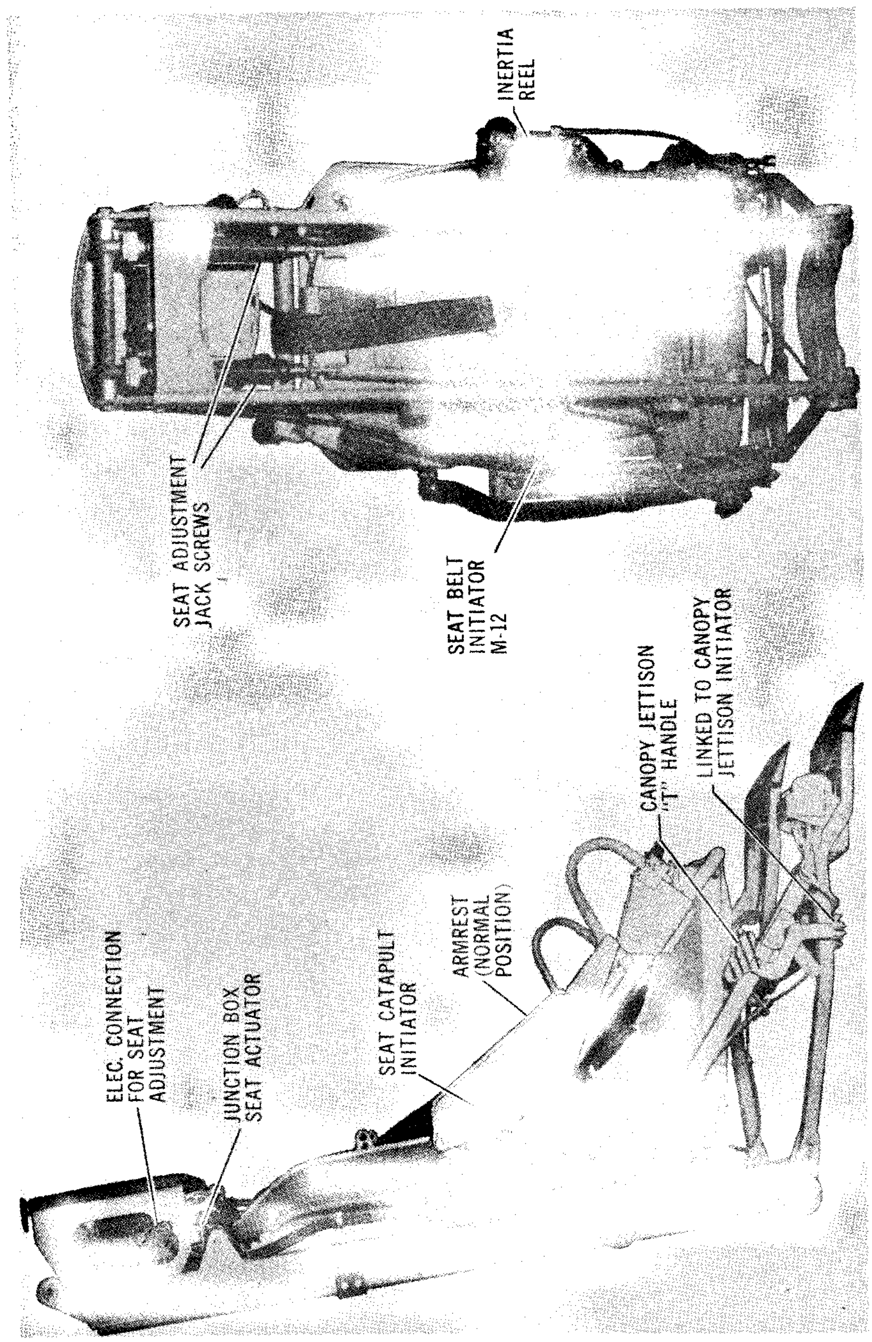


Figure 4-18. Continued.

tion patterns associated with upward velocity changes of this magnitude are (1) a maximum peak acceleration of 25 G, with a duration of .1 to .15 sec., and (2) a 500 G/sec maximum rate of onset.

In upward ejections, an erect posture is required to reduce the possibility of vertebral injury. The buttocks should be pressed firmly against the seatback and the head should be pressed to the headrest with chin tucked in. Proper prepositioning for upward ejection includes tightening of the lap belt and torso harness. This greatly aids in maintaining the proper erect position as the upward acting force is applied. The feet should be positioned in the footrest and the arms on the armrests to prevent their striking the cockpit on ejection. This tends to align the vertebrae so that the force associated with the ejection is evenly distributed over their entire surface. Leaning forward at ejection causes the anterior lip of the vertebrae to be point-loaded as this force is applied. The most common nonlethal injury associated with ejection is a wedge fracture of the lower thoracic and lumbar vertebrae. Forward inclination of the head at ejection tends to produce an exaggerated nod which can lead to cervical vertebral injury.

The cushion used with upward ejection seats also has a marked influence on the tolerability of the imposed forces. Excessive soft-cushioning will be compressed by the seat pan at ejection before the man begins to move. The result is that the seat acquires a velocity before the man and, when the cushion is fully compressed, the seat "runs into" the man, imposing a sharper, more abrupt load than may be tolerable. Crewmen should take care to use cushions, seat-type parachutes, etc., in strict accordance with appropriate technical orders, since these items have been designed to provide the maximum comfort possible without compromising the crewmen during use of ejection systems.

In downward ejection systems, the acceleration magnitude is held to less than 16 G with a rate of onset of acceleration of less than 200 G/sec. The inertial force from downward ejection tends to force the body upward. If the body is restrained against this motion mainly by shoulder straps, the vertebral column is compressed as it is during upward ejection. The difference, however, is that the majority of the load is imposed on the smaller upper thoracic vertebrae which fail at much lower dynamic loads than the lower lumbar vertebrae. Because of this, it is desirable to restrain the body at the pelvis for downward ejections, allowing the vertebral column to be placed in tension rather than compression. Proper prepositioning prior to ejection is also important in this type of system.

The downward ejection seat is equipped with both footrest and foot-retainer devices. The footrest serves merely as a guide for the foot to insure that the foot-retainer device is engaged just above the ankle. The feet tend to rise during downward ejection, and the retainer will prevent this movement. It should be emphasized that use of the footrest during downward ejection is essential to insure clearance of the hatch below the seat. In upward ejection seats, pilots have kept their feet on the rudders until ejected and suffered only slight bruises. However, in the downward ejection seat, correct foot position is imperative. During separation from the seat after ejection, any forward movement of the legs, as might result with exit from the seat, will open the leg retainers.

Upon completion of firing of the catapult, the ejection system encounters the slip stream of the aircraft. The more modern rocket catapults continue to provide thrust during this phase of the escape sequence, attenuating the deceleration resulting from windblast.

Deceleration

In this discussion, the deceleration phase of the escape sequence refers to the first 3 seconds of flight of the escape device after it leaves the aircraft. During this period, the crewman is exposed to sudden deceleration and to a series of complex angular motions whose severity, as previously mentioned, depends on the inherent stability of the escape

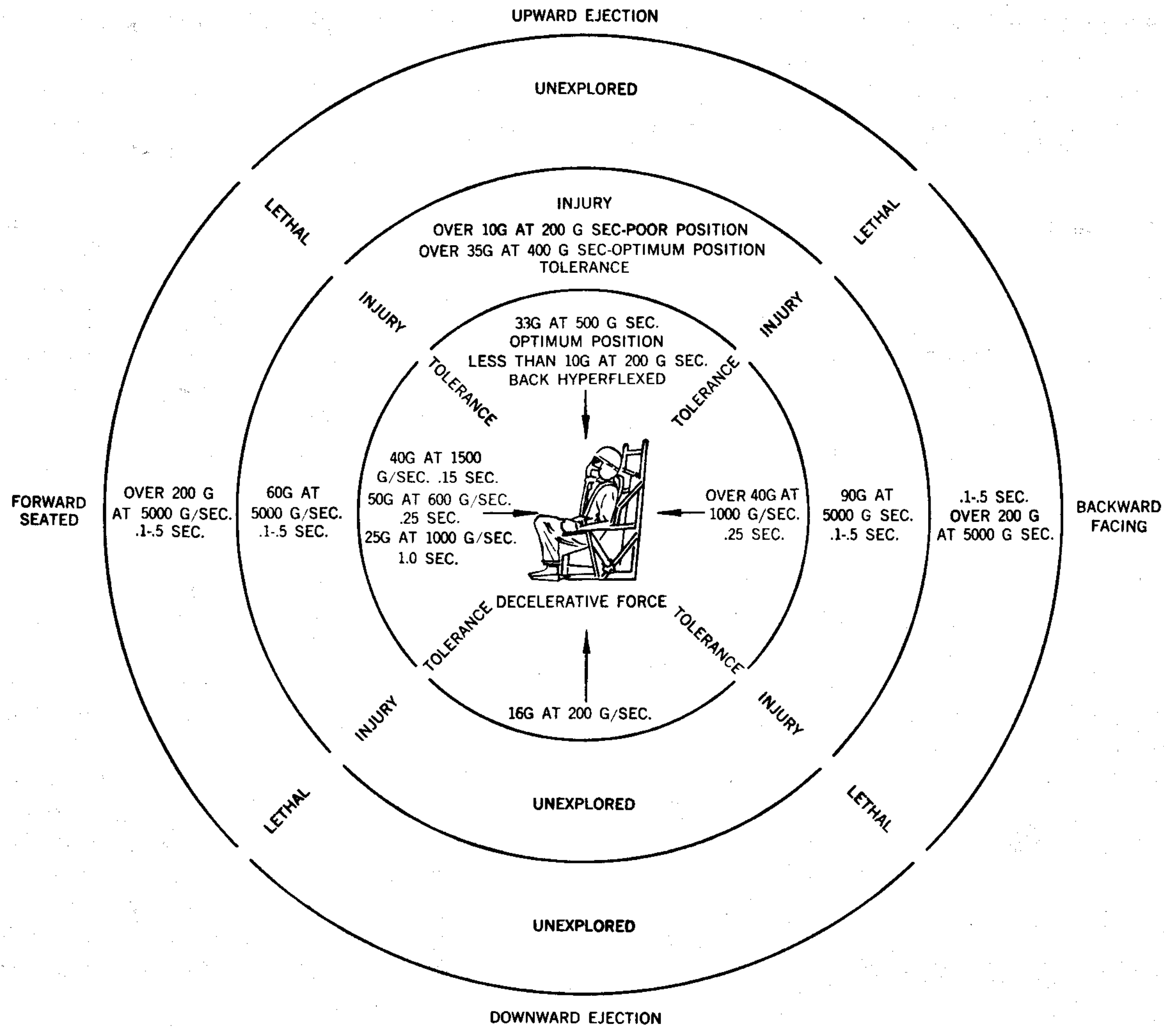


Figure 4–19. Tolerance, Injury and Lethal Limits for Force Applied Through the Principal Axes of Body Orientation.

system and on the initial conditions under which ejection occurs. The crewman is also exposed to an initially higher dynamic air pressure (windblast) which rapidly decays with time after ejection. Windblast and deceleration are most intense during the first second of flight of the escape system. They are usually reduced to insignificant levels after 3 seconds.

Figure 4–19 shows the interrelationship of some of the initial conditions of the aircraft at ejection. It indicates that, as altitude increases, higher speeds must be achieved to attain the same initial Q or dynamic air pressure. While the initial dynamic air pressure in a high-speed, high-altitude ejection may be the same as for a lower speed at lower altitude, it is apparent that the escape device ejected at higher speed possesses a higher kinetic energy. This means that, although the peak deceleration value initially attained may be the same as that encountered at lower altitude and speed, the duration of the deceleration will be prolonged since the escape device must undergo a larger velocity change.

Early ejection seats were essentially aerodynamically unstable in the pitch axis. This

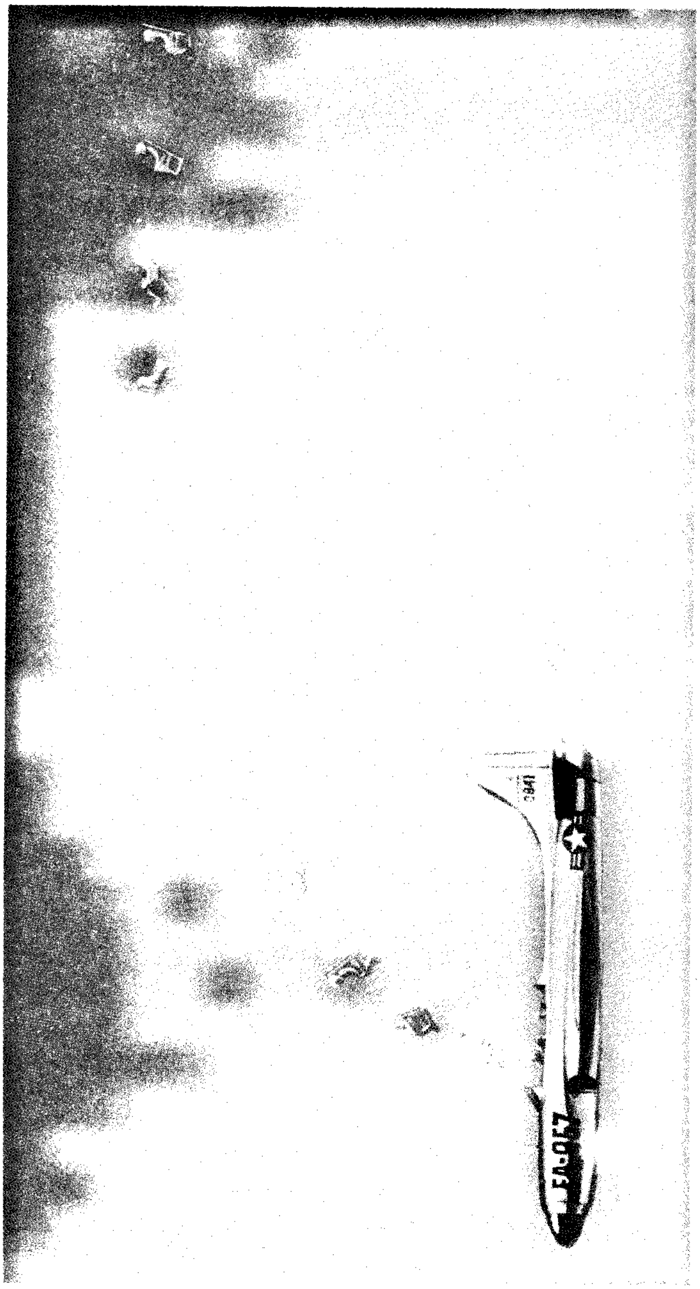


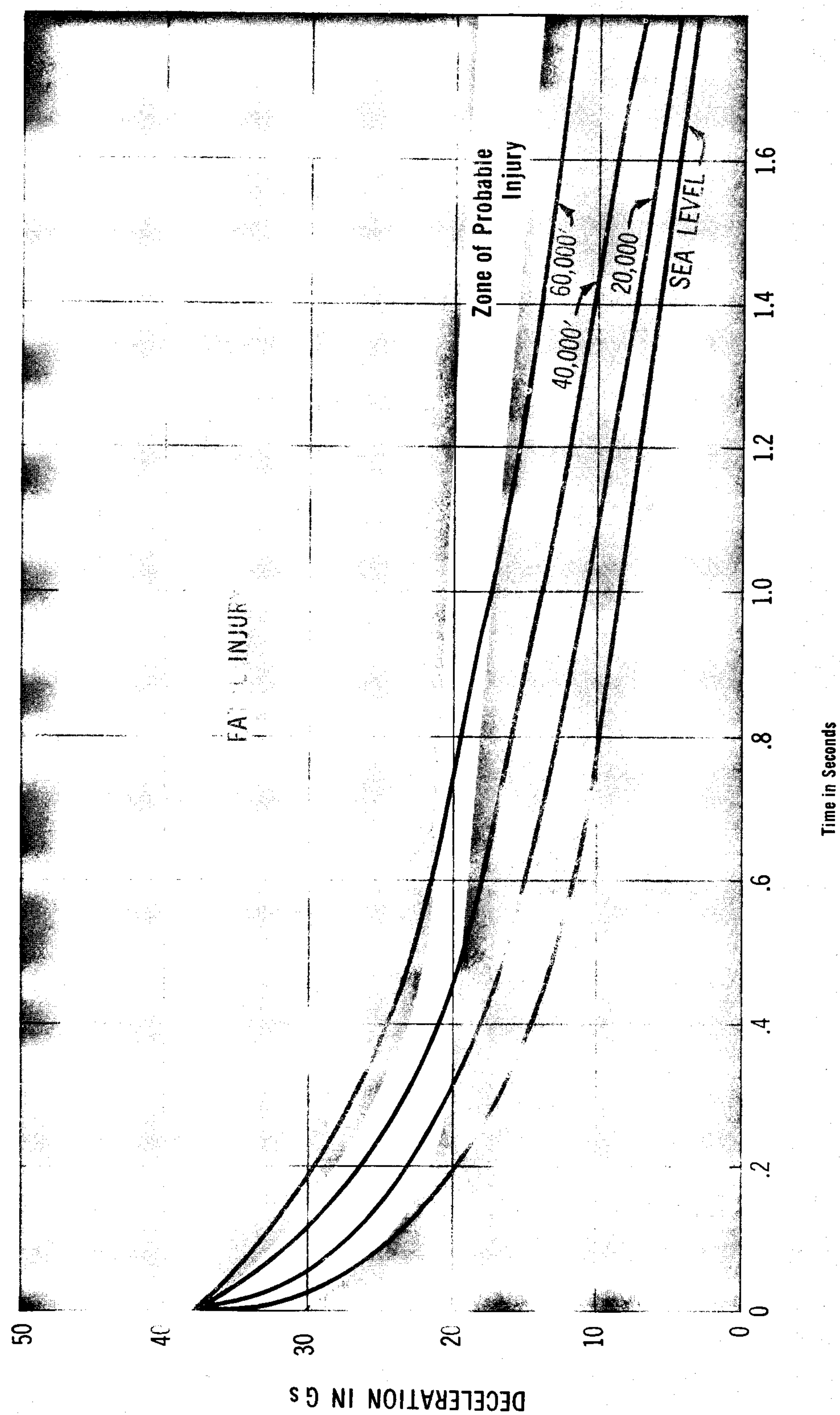
Figure 4-20. Tumbling Effect of an Ejection Seat.

instability produces a head-over-heels type of tumbling at ejection which can reach peak values of as high as 170 rpm for short durations. This tumbling is superimposed on the deceleration produced by windblast. The resultant force applied to the man is complex in that the body tends to change direction with respect to the deceleration vector and, at the same time, is influenced by the centripetal accelerations produced by tumbling. Voluntary human tolerance to sustained simple tumbling (without superimposed linear acceleration) is limited to rates of approximately 100 rpm for 10 seconds. It is assumed that the shorter duration, high amplitude rotary motions are marginally tolerable. The center of rotation for tumbling is usually in the abdominal area. Tumbling causes pooling of body fluids in the head and lower extremities. Rupture of blood vessels in the conjunctivae and, under more severe conditions, in the retinae and in other areas with unsupported vascular beds is produced by tumbling. Ultimately, a reduction in central venous return occurs, resulting in inadequate cardiac output and unconsciousness. Tumbling superimposed on deceleration has been studied in chimpanzees subjected to linear accelerations of 15 G with tumbling at 20 rpm for durations of either 15 seconds or 3 minutes. Severe hemorrhage and hematomas were noted in the head region.

While the primary angular motion in early escape seats was pitching, there was also a tendency for this motion to be combined in a complex fashion with yaw and roll modes. As the speed of aircraft increased, it was necessary to develop some stability in the escape seat to avoid angular motions of higher magnitudes. Semistable ejection systems, as in use in the F–104 and F–106 aircraft usually do not tumble. Instead, they seek the attitude in which they are aerodynamically stable. In so doing, they oscillate about this stable point with motions which decrease in amplitude and increase in frequency with time. There has been some concern in making escape systems too stable because, if ejection occurs with the aircraft in an unusual attitude with respect to the direction of windblast, the very stable escape system will seek its stable position violently, producing accelerations beyond the limits of human tolerability. Devices used to provide increased stability are stabilization booms, drogue parachutes and rockets.

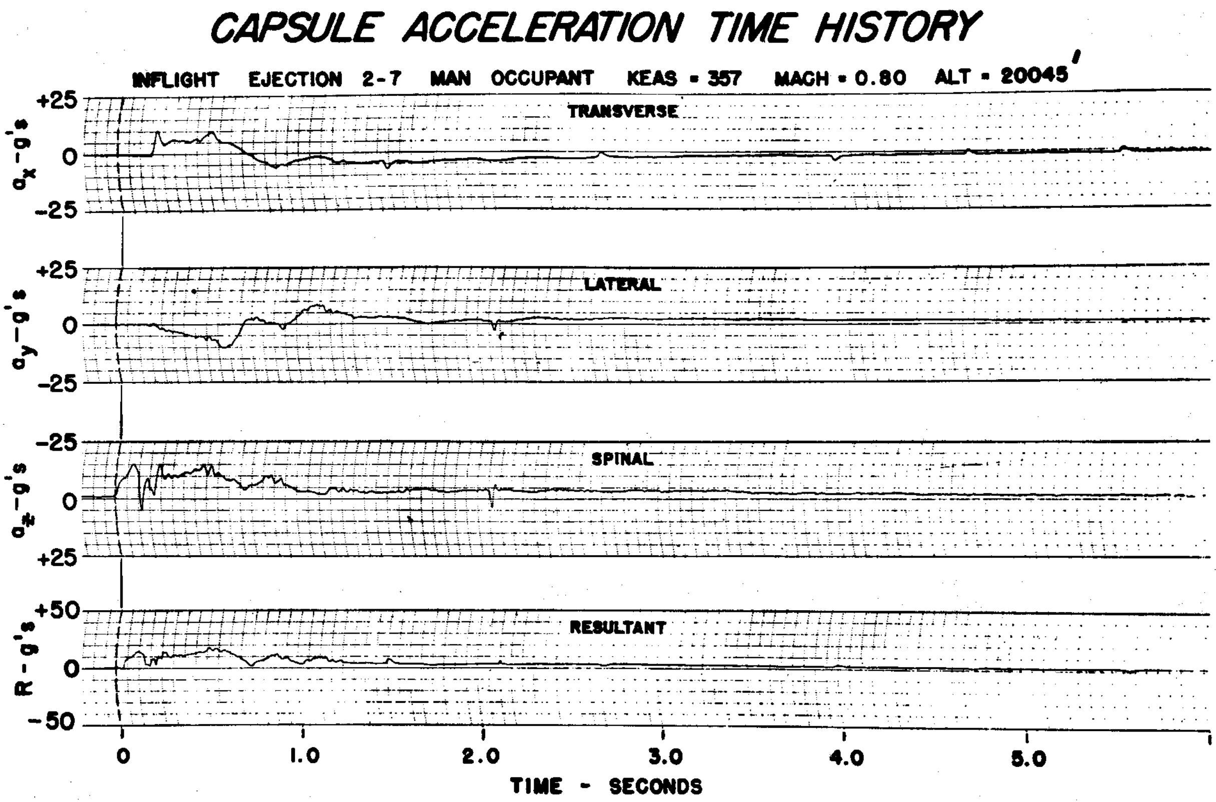
The complex acceleration environment generated by this phase of the escape sequence is illustrated in figure 4–21. Deceleration tends to produce an inertial force which forces the body out of the seat. The thrust of the rocket tends to counteract this and, with low dynamic air pressure, may actually accelerate the system forward, forcing the occupant back into the seat. The magnitude of these decelerations may reach peak values of as much as 40 G. Where semistable escape systems are used, the G-time history is complex and difficult to analyze in terms of tolerability since most experimental data is based on exposing humans to unidirectional single impulses of acceleration. The experimental testing and operational use of escape systems has shown, however, that the general patterns and magnitudes of accelerations in currently used systems are tolerable for the crewman. Current research in this area is oriented toward determining the biodynamic and physiologic responses to changes in magnitude and direction of the resultant acceleration vector such as occur during escape from high-performance aircraft. It is apparent that the requirements for adequate support and restraint are even more stringent during this phase of the escape sequence due to the complexity of the forces generated.

Windblast injuries have been studied extensively, but actual human tolerances have not been determined. Flailing of the extremities and head is known to occur at an equivalent ram pressure of 650 pounds per square foot. This occurs at subsonic speeds. The well-publicized ejection of a North American Aviation test pilot from an F–100 aircraft traveling at Mach 1.05 has furnished some valuable data regarding windblast tolerance in humans. The ejection occurred at an altitude estimated to be between 6,000 and 6,500 feet. Windblast pressure was cal-



(Ref.: WADC Tech. Note 56-7)

Figure 4–21. Injury Potential Related to Decelerative Force and Time.



NOTE: ACCELERATION MEASURED AT CAPSULE SEAT AREA.

Figure 4–22.

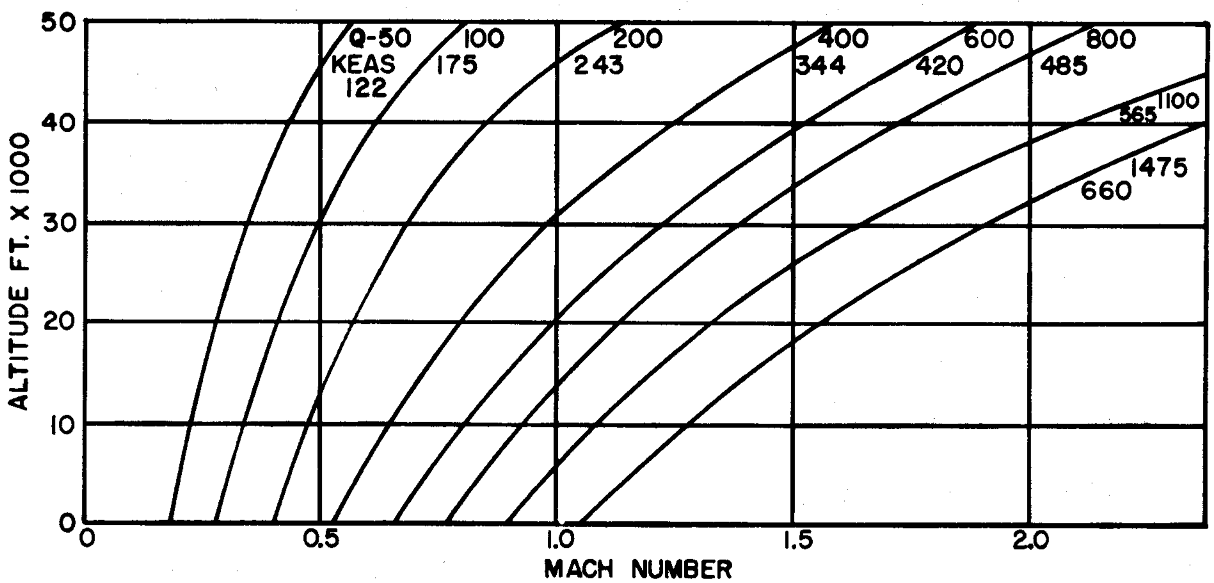


Figure 4–23. Q Force Related to Mach Number and Altitude.

culated to be approximately 1,240 pounds per square foot. Although injuries were severe, they were nonfatal. The major injuries involved gastrointestinal dilation, sustained when approximately three liters of air were blown into the stomach through the nostrils and mouth. Pulmonary damage, as well as burning of exposed body surfaces, has been observed after exposure to very high air pressures. The use of inclosed escape capsules, of course, eliminates the problem of windblast effects on the crewman. It increases the requirements for good restraint, however, since the dynamic air pressure supposedly exerts a positive restraining influence on the man when the deceleration is tending to force him out of the seat with an open ejection system. The deceleration phase of the escape sequence imposes on the crewman greater stress than any of the preceding or subsequent phases. It is during these initial seconds of flight of the escape system that the man is the weakest link in the entire system. Provided he survives deceleration without injury, the success of the remainder of the sequence depends more on the mechanical performance of his equipment than his tolerance to the forces to which he is exposed.

Free-Fall

In emergency ejections, a number of people have mentioned severe tumbling and, in some cases, it has appeared that this may have caused some delay in leaving the seat. In an unstable seat, the situation may be more serious during long falls. More recently developed escape systems are equipped with automatic lap belt release and positive seat separation which tend to reduce this problem. In a number of fatal emergency ejections, crewmen have failed to turn loose the ejection handles after initiating escape, thus staying in the seat and failing to deploy the parachute. Proper indoctrination on this procedure is indicated. The human body is most stable in free-fall when it is in a flat spin with arms and legs extended. At higher altitudes, spin rates may reach values of 150 rpm. The centripetal accelerations produced by spinning produce pooling of fluids in the head and extremities in the same way as prolonged tumbling. Asymmetrical movements of the arms and legs tend to reduce this tendency for flat spinning. The B-58 capsule tends to undergo a helical spinning during its free-fall, but this motion does not exceed tolerable limits. The duration of free-fall, varying with initial altitude, may be as long as 5 minutes with ejections from 50,000 feet. Free-fall is terminated by deploying the recovery parachute.

Parachute Opening Shock

It is a well-known fact that the opening shock of a parachute is greater at high altitude than near the ground. If a parachute causes an 8 G opening shock at 7,000 feet, the same parachute will produce more than 30 Gs at an altitude over 40,000 feet. An understanding of the principles involved is helpful in determining what conditions may produce opening shocks which lead to unconsciousness.

Parachute deployment can be regarded as an air-scooping or filling process. The distance it takes for a parachute to travel sufficient space to fully deploy is related to the size of the parachute, but not to the speed with which it travels. The larger the parachute, the farther it must travel to scoop up the amount of air necessary for deployment. Experiments show that a parachute must travel approximately 8 times its diameter before it is filled.

In contrast to the filling distance, the filling time is related to speed. Since greater speeds provide less time for the parachute to cover the filling distance, greater speeds cause shorter filling time and quicker deployment of the parachute. As speeds at altitude are generally higher than those near the ground, shorter opening time at altitude should be expected. Additionally, in dense air, the billowing of the canopy is somewhat damped. Since this damping is decreased as air density is decreased, opening of the canopy is facilitated at higher altitudes where the air is less dense. Because of the factors mentioned, the time necessary for the deployment of a parachute is shortened

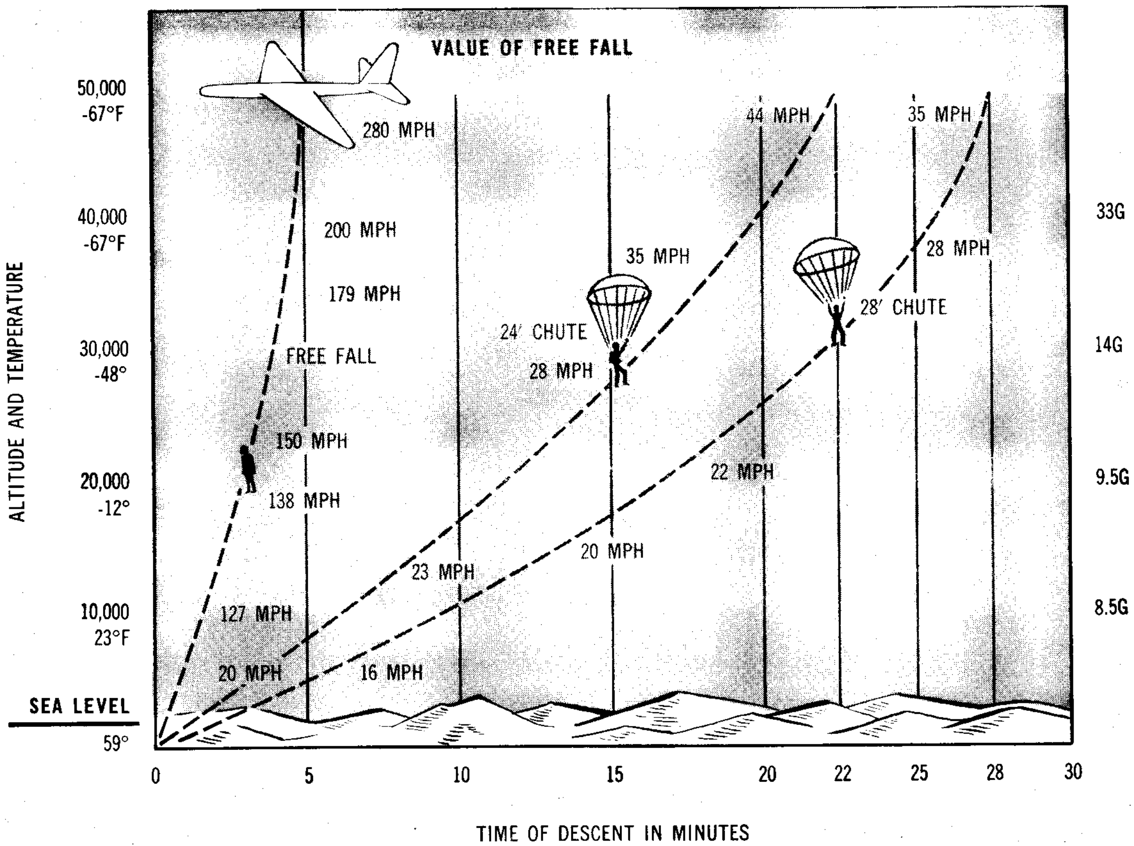


Figure 4–24. Calculated Rates of Descent for Free Fall and Open Parachute From 50,000 Feet and Lower for a Man Weighing 200 Pounds.

by a ratio of 8:1 when comparing sea level to 40,000 feet.

Opening time also has an effect on the amount of the opening shock. In a slowly filling parachute, there is a certain amount of drag induced. This produces some gradual deceleration before the opening shock generated by full parachute deployment. If the filling time is short, little deceleration takes place and full deployment of the parachute occurs at high speed. This can produce a high G opening shock in itself. The newer escape capsules deploy the parachute in the reefed condition, that is, the base of the parachute is gathered so that its diameter is reduced. The chute is then dereefed in approximately 2 seconds. This reduces the magnitude of opening shock.

Another factor involves the velocity of a free-falling body. At sea level, terminal velocity of a free-falling body is about 175 feet per second. The rate of descent of a man in a parachute is about 25 feet per second at sea level. Parachute opening results in a deceleration of 150 feet per second. At 40,000 feet, however, terminal velocity of a free-falling body is 350 feet per second and the rate of descent of a man in a parachute is about 30 feet per second. The deceleration now is 320 feet per second—twice what it is at sea level.

The answer to high-magnitude opening shock is free fall to lower altitudes. Besides avoidance of opening shock injuries, there are other advantages in a free fall after high-altitude escape:

a. There is less danger of getting a parachute caught on the aircraft.

b. Supplemental oxygen is required for a shorter period of time on the way down.

c. The flier is exposed to low temperatures and low air densities for a shorter period of time.

The principal disadvantages to extensive use of free-fall techniques have been the lack of ability to judge height above the ground, a fear of losing consciousness and not recovering in time to pull the ripcord. The answer to this problem has been the introduction of the automatic-opening parachute. The opening device is actuated by either barometric pressure or a timer, both of which may be preset for the desired conditions. According to present technical orders, the automatic parachute-opening device is normally set for 14,000 feet elevation and a 1-second time delay.

This means that if the emergency escape takes place at an altitude in excess of 14,000 feet, the parachute-opening sequence will not be initiated until the man has reached 14,000 feet. At this altitude, the barometric device releases a clock mechanism that runs for 1 second before releasing the power spring actuating the opening phase of the sequence. Below 14,000 feet, the aneroid or barometric portion of the device is automatically bypassed and, once the parachute is armed, the timer operates for one second, then initiates the opening. This combination of barometric and time control permits successful escape over an extremely wide range of speed and altitude. Most escape systems now have the feature of attaching a parachute lanyard between the lap belt and manual D-ring of the parachute. With low-level ejections, the lap belt is automatically released, the lanyard is pulled as the seat and man separate, and the parachute is more rapidly deployed. The lanyard is removed as altitude and speed are reached. Employment of this device has resulted in the saving of life when low-altitude ejection has provided minimal time for parachute deployment.

An emergency escape from above 30,000 feet without oxygen would be extremely hazardous, especially without an automatic parachute. In this situation, hypoxia would be inevitable, with probable failure to regain consciousness in time to pull the ripcord. An open-parachute descent from high altitude without oxygen would subject the man to the combined hazards of high opening shock, excessive cold, and prolonged hypoxia. The wide acceptance of automatic-opening parachutes has removed one of the dangers of high-altitude bailout, but supplemental oxygen is still essential.

The oxygen supply in the H–2 cylinder is adequate for free-fall escape from altitudes up to 50,000 feet. A device in the mask-hose connector prevents oxygen from flowing out the open end of the hose until a pressure of about 15 inches of water is reached. This assures delivery of oxygen under pressure while the man is falling at high altitude. After approximately one minute, the decreased cylinder pressure and the increasing atmospheric pressure decrease the rate of flow from the cylinder and the oxygen is delivered at a lower pressure. Eventually, the oxygen is supplemented with outside air to make up the volume required to fill the lungs.

Landing

Landing with the personnel parachute involves decelerations resulting from vertical velocity changes (sink rate) of approximately 25 feet per second. Horizontal velocities resulting from surface winds may be of varying magnitude. The Army restricts normal practice parachute maneuvers when surface winds exceed 15 mph. The injury rate goes up steeply as landings are made with winds in excess of this intensity. Crewmen should land with knees slightly flexed and attempt to tumble. The parachute should be collapsed as soon as possible. For this purpose, the chute may be disconnected from one shoulder harness with a quick release mechanism. The more common injuries produced by ground landing are sprains and fractures of the lower extremities. In general, however, the body acts as a rather efficient attenuator for the forces produced during landing.

In escape capsules, the attenuating mechanism provided by flexing of the lower limbs is not used since the flier remains in the capsule seat and descends essentially facing the canopy of the parachute. Approximately the same vertical and horizontal velocity changes are encountered with the system as with the personnel parachute. However, the accelerations produced are of much higher magnitude and shorter duration because of the capsule's less efficient attenuation system. Safe landing in this system has been demonstrated in developmental tests with human subjects during impacts with horizontal velocities of up to 20 feet per second. It is assumed to have about the same incidence of injury with increasing surface wind as the personnel parachute above this level.

The other type of landing associated with abrupt accelerations is the crash landing. Crash injuries, fatal and otherwise are, proportionally, more frequent in jet aircraft. In cargo and transport-type aircraft, most injuries occur as a result of failure of aircraft-seat moorings, failure of the shoulder harness inertia reel to lock, and the free-flight of unsecured objects in the cabin of the aircraft. Most survivable injuries in jet aircraft involve vertebral fractures (the direct consequence of vertical decelerative forces) and other traumatic injuries which are a direct result of forceful collapse of the aircraft structure. Protective hard helmets are used in jet aircraft to reduce head injuries.

The comparison in injuries between the front and rear seat passengers in accidents involving two-place jet aircraft is enlightening. Fatalities, as well as major injuries, are higher in the front seat. This is attributed to the following factors:

a. The "slap down" on the front of the aircraft in forced landings and partially controlled crashes. This produces high accelerative forces in the front cockpit, but relatively low magnitude accelerations in the rear cockpit.

b. The shock absorption resulting from deformation of aircraft structure of the front of the aircraft in accidents affords more protection for the rear occupant than for the front cockpit occupant.

The mechanism producing vertebral fractures is usually a vertical force applied from below upward, as the aircraft strikes the ground. This is combined with a horizontal force applied from the front rearward, as the aircraft decelerates while traveling

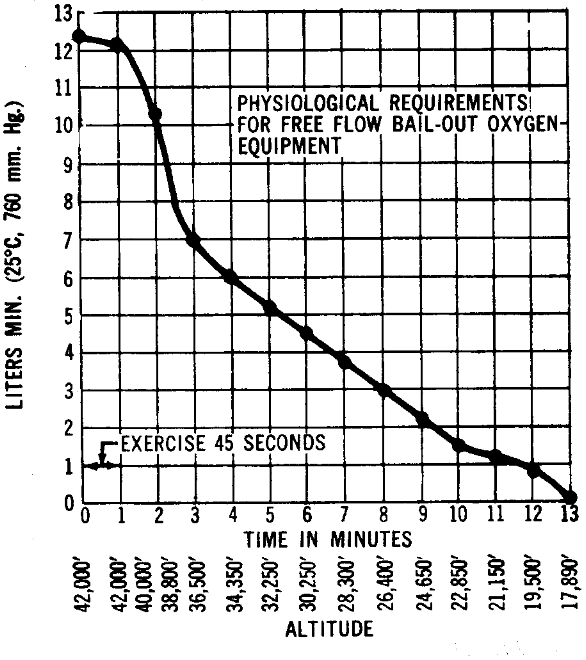
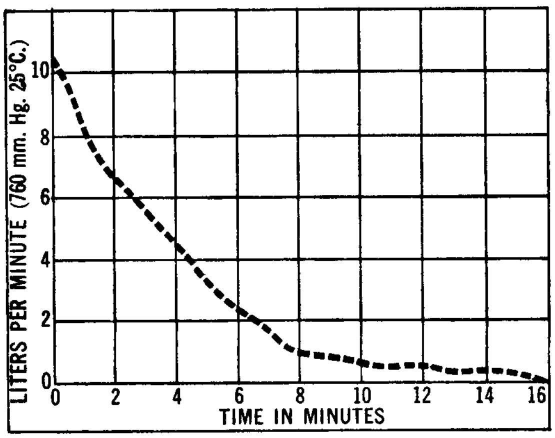


Figure 4-25.



Rate of flow of oxygen from H-2 bailout cylinder at a temperature of 25°C. (77°F.)

Figure 4-26.

Figure 4–27. Typical Method of Removing Injured Pilot From Aircraft, Showing Twisting of Back With Possible Spinal Cord Injury in Pilots With Fractured Vertebra.

along the ground. The injuries in military aircraft correlate well with those encountered in civilian flying. The most frequently affected vertebrae are those at the thoracolumbar junction—*i.e.*, T–12, L–1, and L–2. About one-half of the victims have more than one vertebral fracture. About one-half of the nonfatal vertebral fractures occur when the aircraft first touches down and then encounters an obstruction before coming to rest. The chance for serious injuries is decreased if the aircraft encounters the ground at a low rate of descent and can gradually slide to a stop without any sudden deceleration.

Vertebral fractures should always be suspected among survivors when a major aircraft accident occurs. In addition, forced or hard landings may produce vertebral fracture. The responsible medical officer should be prepared to recognize and handle this type of injury. In removing pilots from cramped cockpits, it is difficult to prevent some extension and twisting of the back. This can result in transection or other severe injury of the spinal cord.

If possible, some device should be used to remove the pilot in his parachute from the cockpit without manipulation of the spine if a vertebral fracture is suspected. Figure 4–28 shows a simple harness, attached to the parachute shoulder straps, which provides a means of removing the pilot in a seated posture. This prevents the stretching, twisting, and compression of the spine as the victim is removed by hand. After removal from the aircraft, the person with back injury should be treated with back support and traction, or by the standard procedures prescribed for treating vertebral fractures.

Flying Helmet. When jet flying was introduced in this country, it became obvious that more substantial head protection than that afforded by the leather flying helmet was needed. The buffeting experienced in high-speed flight required head protection to

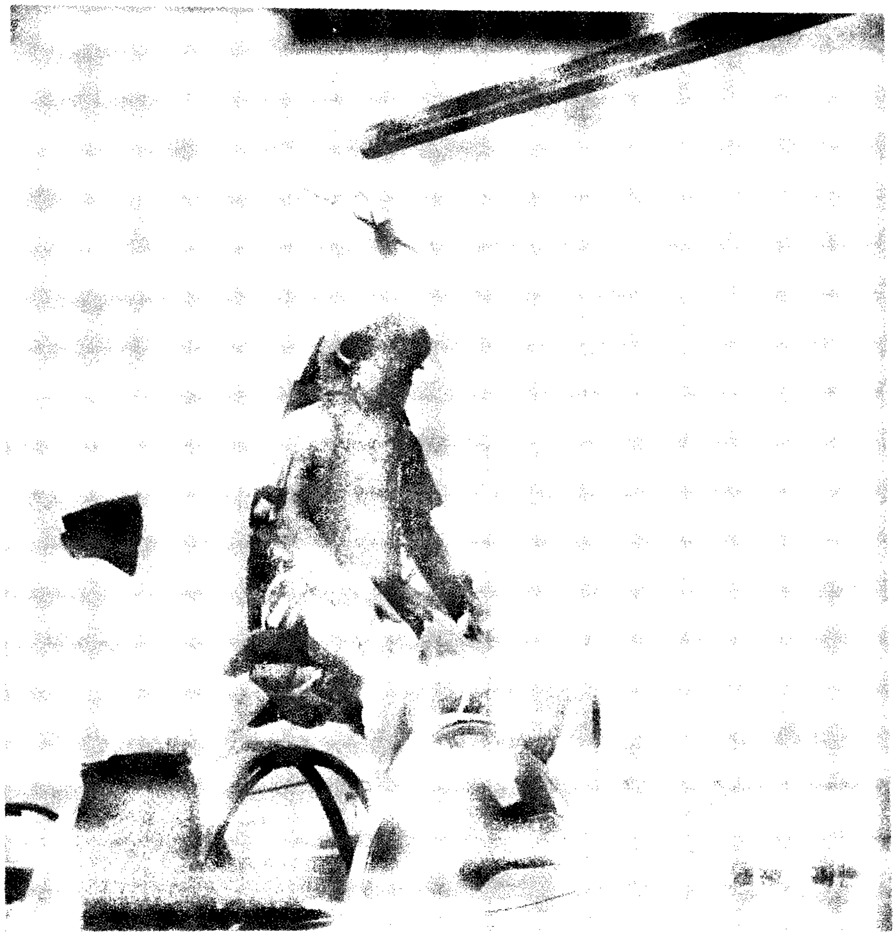


Figure 4-28. Demonstration of Sling Harness Used in Lifting a Back-Injured Pilot From the Cockpit. The Parachute Is Used To Stabilize and Support the Back.

prevent injury in turbulent weather. The first helmet developed for use in jet aircraft was the P-1. This was a rigid plastic shell with a harness-type suspension system for the head. It was equipped for oxygen mask attachment and had an AN/AIC-8 interphone system, but no visor.

When the visor mechanism was added, the helmet became the P-3. When the P-3 helmet was equipped for the use with the AN/AIC-10 interphone system, the type designation of the helmet changed to P-4. The visor mechanism of the type P-4 helmet was modified to insure a more positive locking in the down position, and the type designation was changed to P-4A. The P-4B helmet is identical in all respects to the P-4A helmet except for the communications system.

The H-149 headset is used in the P-4B helmet, and the H-75 headset is used in the P-4A helmet. Both of these headsets are compatible with the AN/AIC-10 intercommunication system. The principal differences between the H-149 and the H-75 headsets, as used in these helmets, are the routing of the cable leads and suspension of the earphone mountings inside the helmet. The P-4B has been, and is, an excellent piece of equipment. It meets the requirements of being light in weight and providing the necessary protection, plus allowing for attachment of oxygen and communication

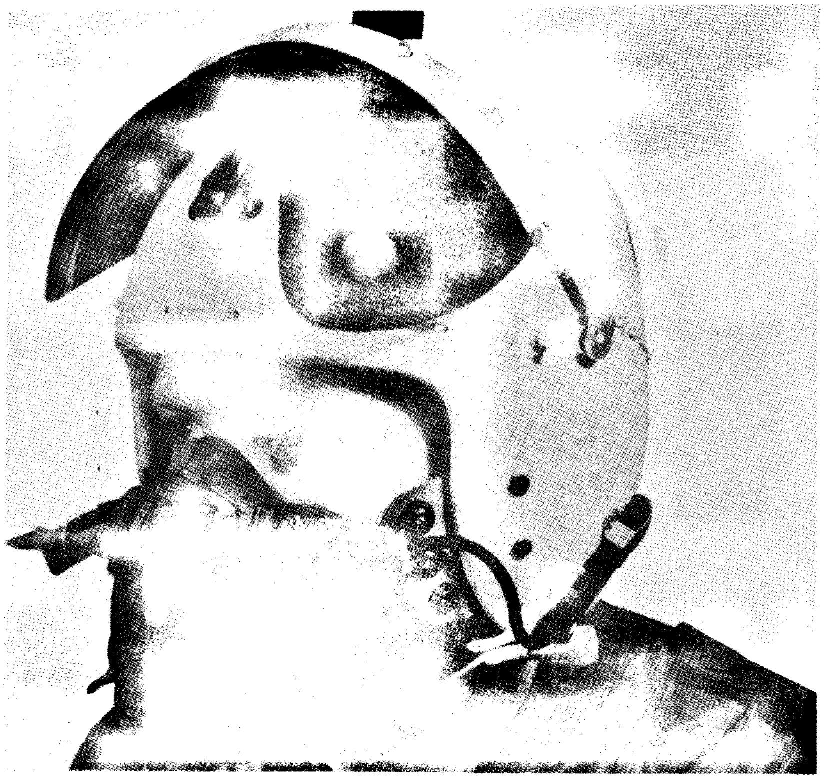


Figure 4–29. The P–4B Helmet.

equipment. However, the P–4B, as all the P-type helmets have been, is uncomfortable to many aircrewmen. The web suspension is difficult to adjust for complete comfort, and it frequently slips out of adjustment.

The HGU–2/P helmet is currently in use, having been designed to replace the P–4 series helmet. It is a rigid molded, reinforced plastic shell with a closely fitted visor assembly. The visor assembly is covered by a visor housing which serves to reduce damage to the lens and adds considerably to impact protection. The principal difference from previous helmet configurations is the use of a foam plastic liner rather than the sling-type suspension. To this liner are attached the helmet fitting pads of proper thickness to adjust the helmet to individual head sizes.

One other helmet deserves mention as it serves partially as an impact protective device. This is the HGU–6/P high-altitude flying helmet. It is used with partial pressure suits, and is designed for use at altitudes above 50,000 feet. Basically, it is a soft helmet. It embodies a bladder for supplying pressure, a detachable rigid molded plastic outer shell to provide protection and retain the pressure within the defined area, and a transparent facepiece.

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