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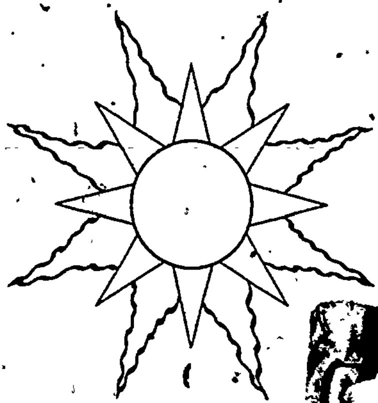
ABSTRACT

This book, one in the series on Aerospace Education III, deals with the general nature of human physiology during space flights. Chapter 1 begins with a brief discussion of the nature of the atmosphere. Other topics examined in this chapter include respiration and circulation, principles and problems of vision, noise and vibration, and self-imposed stresses. Chapter 2 provides an account of aerospace medicine. The next two chapters are devoted to a general description of protective equipment used by fliers, pilot training, and surviving and living in space. Chapters 5 and 6 provide information on skylab and future space flights. The book is designed to be used in the Air Force ROTC program. (PB)

HUMAN REQUIREMENTS OF FLIGHT

AVIATION AND SPACE FLIGHT



Aerospace Education III

Human Requirements of Flight

Aviation and Spaceflight

E. A. Coard
Academic Publications Division
3825th Academic Services Group

AIR FORCE JUNIOR ROTC
AIR UNIVERSITY
MAXWELL AIR FORCE BASE

1974

This publication has been reviewed and approved by competent personnel of the preparing command in accordance with current directives on doctrine, policy, essentiality, propriety, and quality.

This book will not be offered for sale. It is for use only in the Air Force ROTC program.

This text was developed under the directon of 1st Lt Bill D. Brink, Aerospace Curriculum Course Director.

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Preface

As ENGINEERS developed aircraft that could fly higher and faster, greater stresses were placed on the bodies of pilots and aircrews. Man himself soon became the factor limiting advances in flight. To enable man to overcome his natural handicaps and to progress in flight into the cold, rarefied atmosphere, doctors and physiologists have had to learn more about the way the body reacts to flight.

As medical specialists have accumulated knowledge about flight physiology, they have worked with engineers to meet the human requirements of flight. By designing and developing oxygen masks, pressure suits, and pressurized cabins, medical and engineering specialists have enabled man to protect his body while flying in the upper atmosphere. With more advanced protective clothing and equipment, man could progress to the very fringe of space and then into space itself.

Pioneer balloonists, pilots, and astronauts have also played an important part in meeting the human requirements of flight. First came the balloonists who explored the lower reaches of the atmosphere. Next came the test pilots and the combat pilots who flew the newest models of high-performance aircraft. Even after high-performance aircraft were flying, balloonists continued to explore the atmosphere at higher altitudes until they reached the flight ceiling. The animals sent aloft on sounding rockets and in spacecraft helped to prepare the way for man to go into space. The first astronauts who orbited in space and traveled to the moon were subjected to flight stresses much greater than man had ever before encountered.

As man has learned better ways for countering the stresses of flight at higher altitudes, flight has become safer and more comfortable. Commercial air transportation has expanded rapidly as a result.

In compiling this book, information was obtained from many sources. Grateful acknowledgment is made to the Federal Aviation Administration (FAA) and to the airlines for information on pilot training. Thanks are also due to the National Aeronautics and Space Administration (NASA) for photographs showing man's activities in space, as well as for information on space projects and schedules. Information on the physiological effects of space radiation was obtained from publications of the US Atomic Energy Commission and the Air University *Space Handbook*.

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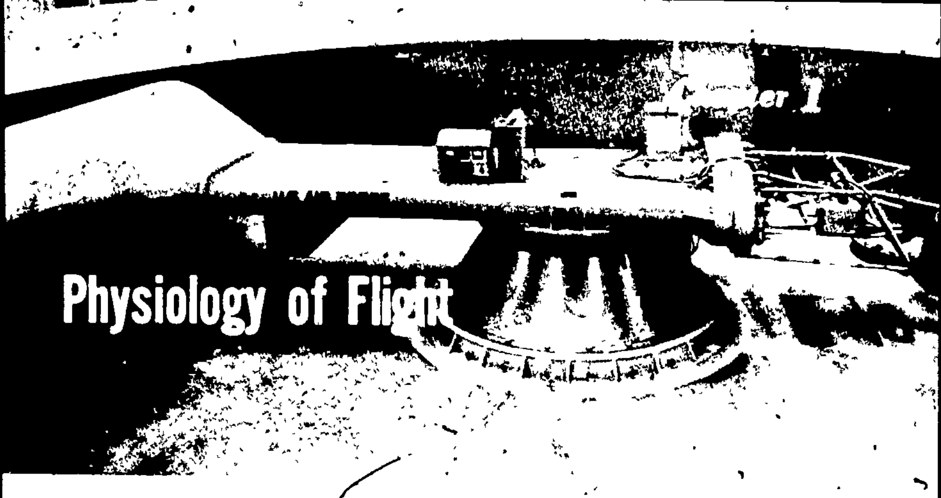

Physiology of Flight

THIS CHAPTER summarizes the basic principles of the physiology of flight. It describes the nature of the different layers of the atmosphere, and it explains how the respiratory and circulatory systems are affected by reduced barometric pressure at altitude. It describes the causes and symptoms of hypoxia, trapped gases, and decompression sickness, and the effects of rapid decompression at altitude. It also explains how the eyes function during flight and how the flier's body is affected by disorientation and motion sickness, increased G-forces, noise and vibration, excessive heat and cold, noxious gases and vapors, and self imposed stresses. After you have studied this chapter, you should be able to do the following. (1) tell the principal differences between the layers of the atmosphere through which aircraft fly, (2) explain how a flier is affected by hypoxia, trapped gases, decompression sickness, and rapid decompression at high altitudes, (3) explain why good eyes are important to a flier, and (4) describe how a flier is affected by disorientation, noise and vibration, excessive heat and cold, and self-imposed stresses (alcohol, tobacco, and drugs).

MAN'S NATURAL ENVIRONMENT is on the ground at the bottom of an ocean of air. As man began to leave his natural environment and fly aircraft to high altitudes, he found that the pressure of the surrounding air decreased with increasing height, and that he experienced stress in the cold, rarefied air. As man flew to increasingly higher altitudes and at greater speeds, additional stresses were placed on the body If man was to continue to progress in flying, he had to learn more about the human body and the way in which it is affected by flight.

Man has learned many ways to adapt to flying as aviation and spaceflight have progressed This adaptation has been brought about not by learning how to make the body change but rather by using special equipment or changing the body's environment during flight The human body makes changes only within narrow limits in attempting to adjust to the stresses of flight. The body tissues maintain essentially the same temperature, have about the same concentration of oxygen and salts, and are bathed by a similar amount of fluid during flight as on the ground. One of the principal ways that man keeps his body functioning normally during flight is to create an earthlike environment that he can take with him while he is flying.

NATURE OF THE ATMOSPHERE

In his natural environment on the ground, man maintains a uniform pressure inside and outside the body. The atmosphere provides the body tissue with a supply of **oxygen,** which is necessary to sustain life. The human body can adjust to relatively small temperature changes, and it can survive for some time without food or water; but life cannot be sustained for long without oxygen. At sea level, a man shut off from oxygen provided by the atmosphere would die within five to eight minutes. At high altitudes, death would come sooner.

To understand how the body is affected by the atmosphere during flight, it is necessary to know more about the atmosphere and how it changes with altitude.

Composition of the Atmosphere

At sea level the atmosphere is made up of a mixture of many gases and varying amounts of water vapor. The proportions of the different dry gases in the lower atmosphere remain fairly constant. Of the mixture of dry gases at sea level, roughly 78 percent is nitrogen and 21 percent is oxygen. The remaining 1 percent consists of carbon dioxide and other gases.

Although **nitrogen** makes up about 78 percent of the atmosphere, it is not used by the body to support life. Nitrogen serves only to dilute the oxygen and supply additional pressure, and the same amount of nitrogen is exhaled as is inhaled. It is important to remember that the blood and other body fluids contain nitrogen. This gas may change from the liquid to the gaseous state during ascent to high altitudes.

Oxygen must not only be taken into the lungs but also be absorbed into the bloodstream and carried by the blood to all parts of the body. Oxygen must be constantly supplied to the cells and tissues to keep the body alive. As man ascends to higher altitudes, he finds that the amount of oxygen decreases and that the temperature and pressure of the atmosphere also change.

Layers of the Atmosphere

The atmosphere is usually divided into the troposphere, the stratosphere, the ionosphere, and the exosphere. Between each region is a transition layer (-pause), as shown in Figure 1. The depth of the different layers of air varies with the time of day, the season, and the geographical location. (Average depths are given in the figure.)

We live in the **troposphere,** and most flying takes place within this layer. Its average depth is 35,000 feet; and most of what we refer to as weather—that is, winds, storms, rain, snow, hail, and clouds—occurs in this division. The wind in the troposphere usually increases with altitude, and the swift jet streams are found at the higher altitudes near the tropopause.

When a pilot flies above the tropopause and is in the **stratosphere,** he is above most weather. There is very little moisture and cloudiness in the stratosphere. In this division neither the supply of oxygen nor the pressure of the atmosphere is adequate to sustain life. Most of the larger jet transports fly in the lower stratosphere or in the upper troposphere.

Within the **ionosphere** the atmospheric pressure continues to decrease with height; and, as the name suggests, this region is characterized by ionization of atmospheric particles by solar radiation.

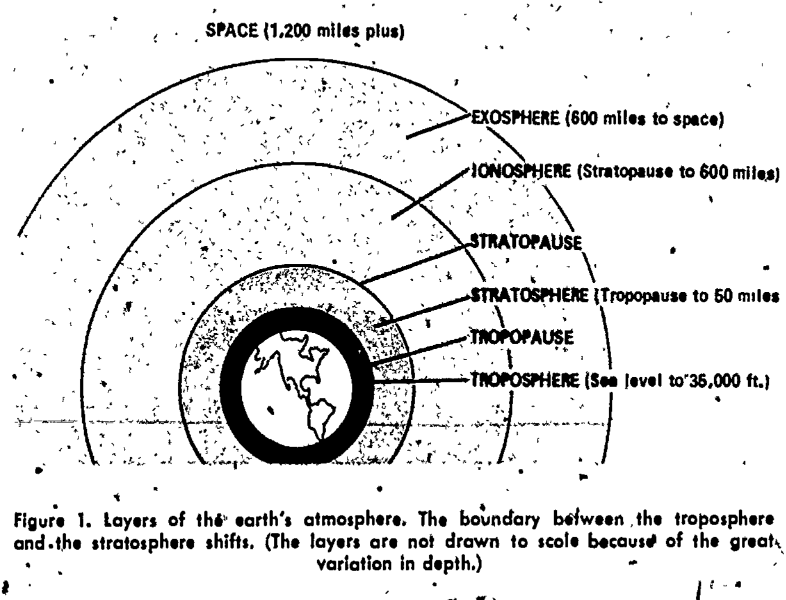

Figure 1. Layers of the earth's atmosphere. The boundary between the troposphere and the stratosphere shifts. (The layers are not drawn to scale because of the great variation in depth.)

In the **exosphere,** which extends from about 600 to 1,200 miles above the earth, atmospheric density continues decreasing with altitude until a region is reached where particle density is so small that we call it space. In the exosphere there are so few molecules that they seldom strike against each other. Only spacecraft can operate in the exosphere and the ionosphere.

Within the troposphere, or the lowest level of the atmosphere, the temperature decreases with an increase in altitude. Within the stratosphere, the temperature remains fairly constant. Temperature characteristics of the US Standard Atmosphere are given below:

Altitude in feet	*Temperature in degrees F.*
0	59.0
10,000	23.4
20,000	−12.3
30,000	−47.8
40,000	−69.7
50,000	−69.7
60,000	−69.7

As the air continues to become less dense with increasing height within the exosphere, the classic concept of temperature is no longer applicable, since temperature no longer depends upon the energy of the gas molecules.

Space, considered from a purely physical standpoint as almost total absence of air molecules, begins at about 1,200 miles. Space as it affects the human body begins at a much lower altitude, at about 50,000 feet. In the study of flight physiology other divisions of the atmosphere, called the physiological zones, are used.

Physiological Divisions

Since pressure variations affect the body in different ways, the flight environment is divided into the physiological zone, the physiological-deficient zone, the partial space-equivalent zone, and the total space-equivalent zone (Fig. 2).

Pressure within the atmosphere is measured with a barometer and is expressed in terms of the height of a column of mercury (Hg) which could be supported by a given atmospheric pressure. At sea level, where atmospheric pressure averages 14.7 psi (pounds per square inch), the atmosphere supports a column of mercury 29.92 inches high. In flight physiology, atmospheric pressure is usually measured in millimeters (mm) rather than inches. The pressure of the atmosphere at sea level is said to be 760 mm of Hg, or pressure strong enough to support a column of mercury 760 mm high. The physiological zone begins at this pressure level.

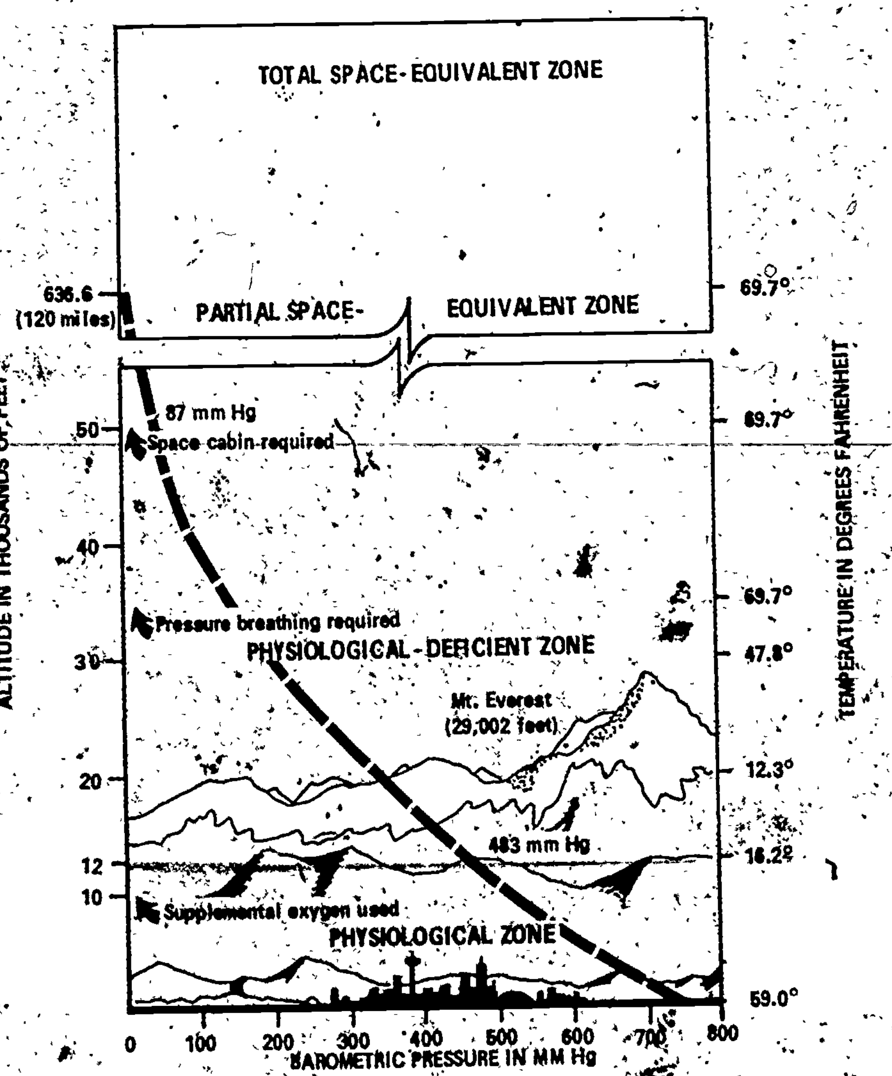

Figure 2. Physiological divisions of the atmosphere. Above the physiological zone man must have supplemental oxygen and protective equipment. The Air Force begins to use supplemental oxygen at the 10,000-foot level.

PHYSIOLOGICAL ZONE.—The **physiological zone,** or the region of the atmosphere within which man is physiologically adapted to flight, extends from sea level to 12,000 feet. Within this zone there is enough oxygen to allow a normal, healthy man to fly without the use of special protective equipment, and it is within this zone that the majority of flying is done. Man may experience some dizziness or discomfort in the ears or sinuses when he makes an ascent or a descent too rapidly within this region, but these changes in the body usually do not produce physiological impairment. At the lower limit of the physiological zone, atmospheric pressure is 760 mm Hg, and it drops to 483.4 mm Hg at the upper limit. Although it is possible to survive above 12,000 feet without an oxygen mask, the Air Force requires its personnel to use supplemental oxygen when flying above 10,000 feet.

PHYSIOLOGICAL-DEFICIENT ZONE.—From 12,000 feet up to 50,000 feet extends the **physiological-deficient zone.** Atmospheric pressure decreases from 483.4 mm Hg to 87.4 mm Hg within this second zone. With the reduced atmospheric and oxygen pressure, man must be supplied with supplemental oxygen, and at the higher levels the oxygen must be supplied under pressure. Most military aircraft and commerical aircraft flying long distances go into this second zone. Flight within the zone is made possible through the use of protective equipment.

PARTIAL SPACE-EQUIVALENT ZONE.—The **partial space-equivalent zone** extends from 50,000 feet to 120 miles above the earth, an extensive area. Within this third zone the atmospheric pressure is so low that a man would lose consciousness even if supplied with 100 percent oxygen under pressure. Aircraft flying within the partial space-equivalent zone must have a completely sealed cabin, or what is known as a space cabin. In the inclosed space cabin, oxygen is supplied from within, and carbon dioxide must be removed and the air purified. Pressure suits are needed for additional protection.

Aircraft and balloons can operate only in the lower reaches of the space-equivalent zone. At about 20 miles above the earth the atmosphere can no longer support balloons or most winged aircraft. Man can go beyond this altitude only when he travels in a special rocket-powered aircraft or a spacecraft.

TOTAL SPACE-EQUIVALENT ZONE.—Beyond 120 miles from the earth is the **total space-equivalent zone.** In this zone the environment has all the characteristics of true space as far as the human body is concerned. The special problems of flight within this zone are described in Chapter 4. In this chapter we are concerned only with the general problems of flight physiology, especially those that arise from reduced atmospheric pressure at altitude. To understand how the human body is affected by reduced pressure, it is necessary to know the laws governing the action of gases.

Physical Laws of Gases

The human body is both a living organism and a structure with many air-filled cavities and with canals and tubes that have fluids in them subjected to atmospheric pressure. As the body ascends to higher altitudes and the atmospheric pressure decreases, the gases within the body act according to physical laws. These are principally Boyle's law, Dalton's law, and Henry's law.

BOYLE'S LAW.—Boyle's law states that the volume of a gas is inversely proportional to its pressure if the temperature remains constant. In other words, when the pressure of a gas decreases at constant temperature, its volume increases, and vice versa. This law explains why the gases trapped in the body expand as the atmospheric pressure on the outside of the body decreases with increasing altitude.

DALTON'S LAW.—Dalton's law states that the total pressure of a mixture of gases is equal to the sum of the partial pressure of each gas in that mixture. This law has an important application in computing the pressure required for an artificial breathing atmosphere for aircraft and spacecraft.

Fortunately, the pressure of a pure-oxygen atmosphere in a space suit can be made to be about the same as the partial pressure of oxygen at sea level; the total atmospheric pressure, or 14.7 psi, does not have to be used. Since oxygen makes up about 21 percent of the atmosphere at sea level, the normal pressure of oxygen at sea level is about 3.09 psi. A slightly higher pressure is used to provide a safety factor. This means that an astronaut is safe with an oxygen pressure of about 3.5 psi in his space suit, which he depends upon for only a relatively short time when outside the spacecraft. For the oxygen atmosphere inside the spacecraft, which the astronaut breathes for extended periods, engineers use a pressure of about 5 psi.

HENRY'S LAW.—Henry's law states that the amount of a gas in solution varies directly with the partial pressure that this gas exerts on the solution. This means that when the partial pressure of a gas decreases with altitude, that gas evolves, or comes out of solution from the blood or other body fluids. Henry's law explains why nitrogen and other gases escape from solution and form innumerable tiny bubbles in the body as the ambient, or surrounding, pressure decreases.

The problems caused by evolving nitrogen make up some of the most serious problems of flying at high altitudes. The more frequent problems, however, are those due to lack of oxygen. These directly affect respiration and circulation.

RESPIRATION AND CIRCULATION

Respiration is the process by which the body exchanges gases with the environment. The parts of the process that are most familiar to us are the inhalation of oxygen and the exhalation of carbon dioxide. Actually these are only two parts of a much more complicated process. Respiration includes all the steps entailed in taking oxygen into the body, carrying the oxygen to the cells to support oxidation of food, and removing carbon dioxide from the body.

The respiration process is closely related to the circulation of blood throughout the body. Although all processes and systems

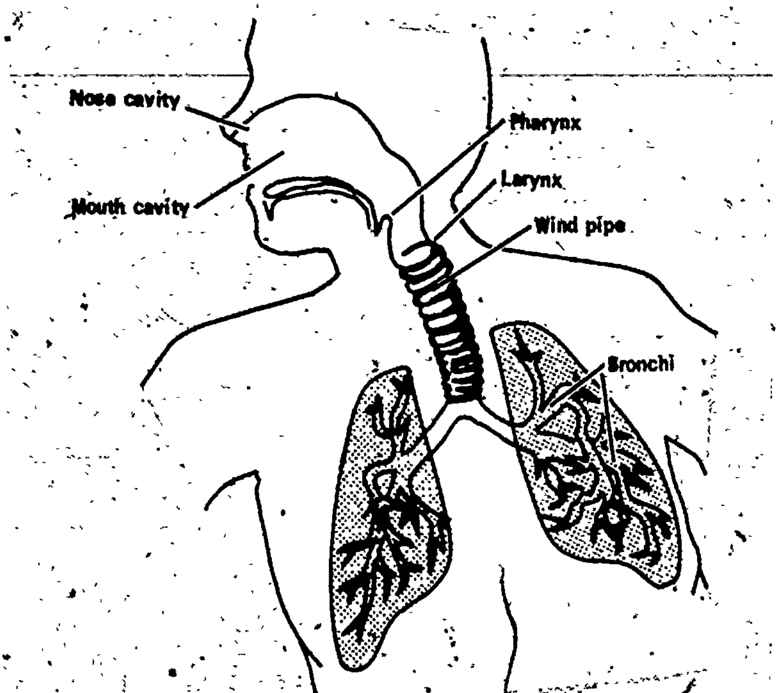

Figure 3. Respiratory system. This includes the air passages of the nose and throat, the windpipe, the bronchi, and the rest of the lungs.

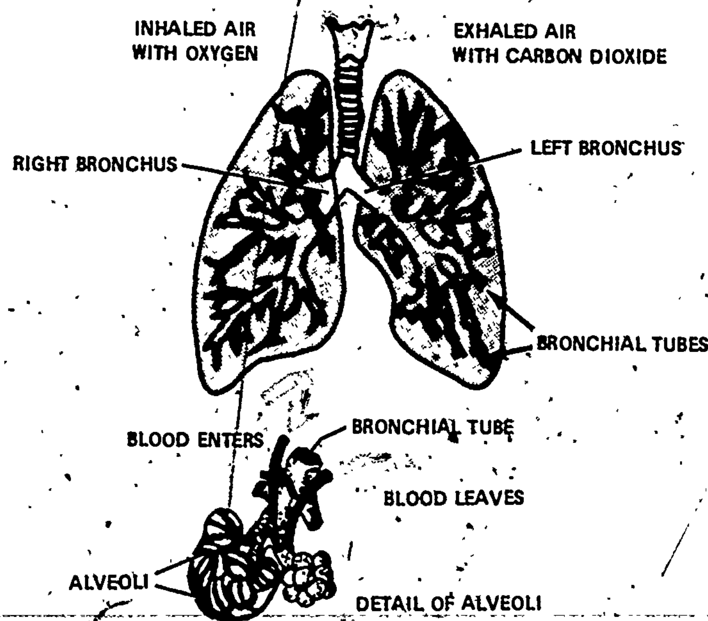

Figure 4. Lungs with alveoli. The air finally passes into the millions of tiny alveoli in the lungs. Here the air enters and leaves the bloodstream.

of the body are in some way affected by the stresses of flight, the respiratory and circulatory systems are most directly affected.

The stress placed on the body by decreasing oxygen pressure first affects the respiratory system itself. The respiratory system is made up of the lungs, a series of conducting tubes called **bronchi,** the windpipe, and the mouth and nose (Fig. 3). Air first enters the nasal passages, where it is warmed and moistened and small particles of foreign matter are removed. The air then passes down the throat, through the windpipe, into the bronchial tubes, and then into the lungs. Once inside the lungs, the air goes through many thousands of small tubes that branch off from the large tubes (Fig. 4). Located at the very end of each branch is a minute air sac, known as an alveolus (plural, **alveoli**). There are estimated to be about three hundred million alveoli in the lungs. Surrounding the thin, moist wall of each aveolus are tiny blood vessels, or capillaries. Because the walls of the alveoli and the capillaries are very thin (1/50,000th of an inch), gases in solution can pass back and forth into and out of the blood which flows through the capillaries.

Oxygen passes from the alveoli into the bloodstream because the partial pressure of oxygen in the alveoli is greater than that in the bloodstream. Air, like water, seeks its level, passing from an area of higher pressure into one of lower pressure.

Once the supply of oxygen enters the bloodstream from the lungs, it is circulated throughout the body by the action of the heart. The heart is an organ for pumping blood throughout the body. For doing this, the heart has four cavities: two **atria** and two **ventricles.** (Fig. 5). The left atrium receives the oxygen-rich blood from the lungs and passes it to the left ventricle. The left ventricle forces this oxygenated blood through the arteries to supply the tissues. The right atrium receives the venous blood after it has passed through the capillaries and given up its oxygen. The venous blood then passes to the right ventricle and then to the lungs to be supplied with oxygen again. The arteries carry the oxygen-rich blood away from the heart to the body tissues, and the veins carry the deoxygenated blood back from the tissues to the heart.

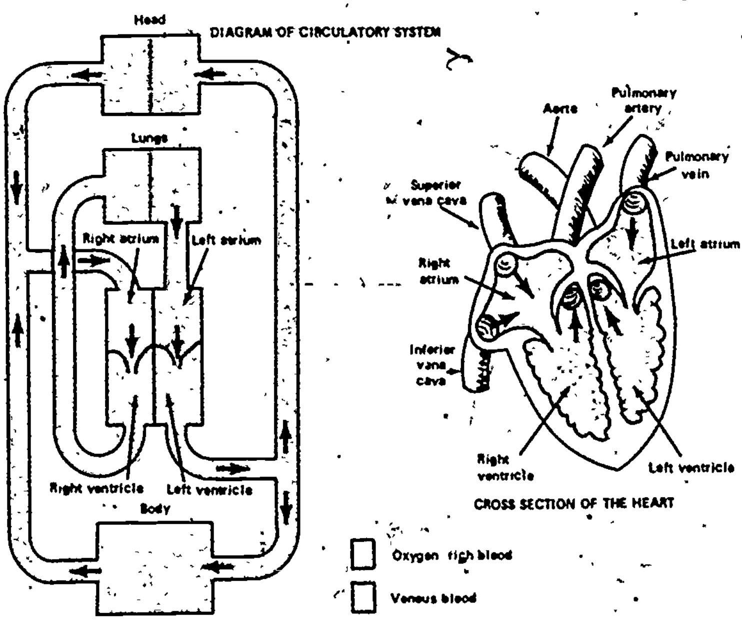

Figure 5. Circulatory system. The heart has four cavities for receiving and sending out blood. These are the right atrium, the right ventricle, the left atrium, and the left ventricle. The red blood is the oxygen-rich blood. The venous blood has had the oxygen taken from it.

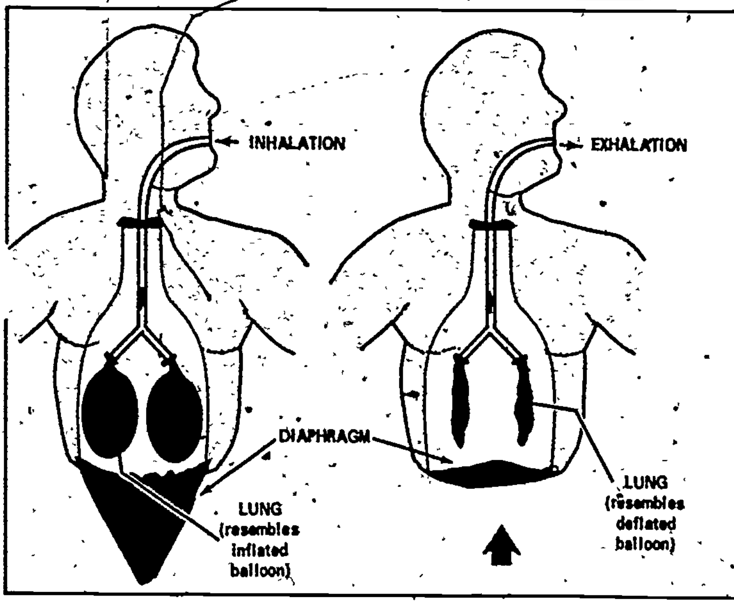

Figure 6. Mechanics of breathing. At inhalation the diaphragm moves downward (left), the lungs expand, and air enters the lungs. At exhalation the diaphragm moves upward (right), the lungs contract, and air is forced out of the lungs.

The amount of carbon dioxide in the blood has an important effect on the action of the heart. As the concentration of carbon dioxide in the blood increases, it causes the heart rate to speed up so that the heart can send more oxygenated blood to the tissues. When the amount of carbon dioxide in the blood decreases, the heart rate is slowed down because less oxygen is needed by the tissues.

Similarly, the respiratory system acts to keep the amount of oxygen in the body tissues constant. To make up for reduced oxygen pressure at altitude, man begins to inhale more rapidly. The mechanical processes that control inhalation and exhalation of oxygen in breathing had to be understood before engineers could design oxygen masks and pressurized cabins.

The lungs are like two balloons that almost fill the cavity known as the **thorax** (Fig. 6). This cavity is bound by the rib cage and by the **diaphragm**. The ribs extend from the spinal column (to which they are attached) to the front part of the body. The ribs are connected by means of muscle tissue that expands and contracts with the action of the diaphragm. The diaphragm is a dome-shaped structure also made up of muscle tissue. It separates the thorax from the abdominal cavity, which lies below it.

As the diaphragm moves downward and the ribs move outward, the thorax expands and increases in volume. With increased volume, the pressure of the gases in the thorax and lungs decreases, and air rushes in from the outside, causing the lungs to expand and fill. This is the **inhalation** phase of the **respiration cycle.** When the air in the lungs reaches the same pressure as that in the ambient air, the muscles relax and the diaphragm moves upward, causing the thorax to contract. With decreased volume, the pressure of the gases in the thorax and lungs increases, forcing the air out of the lungs. This is the **exhalation** phase of the respiration cycle.

If you keep in mind the working of the respiratory and circulatory systems of the human body, as well as the laws governing the physical action of gases, you will understand how the body is affected by reduced atmospheric pressure at altitude.

EFFECTS OF REDUCED PRESSURE AT ALTITUDE

As the body ascends to high altitudes, it must make adjustments to the reduced atmospheric pressure in order to keep the body tissues constant. If the pressure outside the body is greatly reduced and the body is not adequately protected, it cannot make the necessary adjustments, and injury, sickness, and death may result. As the pressure acting on an unprotected body decreases, the most frequent result is hypoxia.

Hypoxia and Hyperventilation

Any pilot who flies above 12,000 feet, or goes into the physiological-deficient zone, without supplemental oxygen is likely to develop symptoms of hypoxia. Prospective pilots must learn about the symptoms and effects of hypoxia because the onset of the condition may be sudden and unsuspected.

Hypoxia can be defined as a deficiency of oxygen in the body cells or tissues. Hypoxia in flight is usually caused by an insufficient amount of oxygen in the inhaled air, but it may be aggravated by other conditions, such as anemia, poor circulation of the blood, or the presence of poison or alcohol in the body. The greatest danger from hypoxia in flight occurs when the pilot or a member of the aircrew becomes so engrossed in his duties that he does not notice the first symptoms of hypoxia. In such cases the hypoxic condition may become so serious that protective measures cannot be taken. For this reason each pilot and aircrew member is trained to recognize his own personal symptoms of hypoxia. To help him do this, he is exposed to low pressures simulated in an altitude chamber, or an airtight tank. One way of recognizing symptoms of hypoxia is to take samples of a trainee's handwriting as he is exposed to different levels of reduced pressure. The handwriting will frequently show the effects of hypoxia even before the trainee is aware that he is affected.

When aircraft first began flying above the 15,000-foot level and pilots began to suffer from hypoxia, they reacted in different ways and it was difficult to pinpoint the trouble. This was especially dangerous because hypoxia causes mental as well as physical disturbances. Under the effects of hypoxia, some pilots became depressed, but most pilots became bold and elated, much as if they were intoxicated. Even though they had paid close attention to orders in the past, they suddenly disregarded all commands. They sometimes went into fits of laughter as they took their aircraft higher and higher, unaware of the danger, until they finally lapsed into unconsciousness.

Now the effects of hypoxia are better understood, but the symptoms still cannot be precisely defined, as they vary from person to person. The symptoms at first may include an increased breathing rate, dimming of vision, headache, dizziness, poor coordination and impairment of judgment, and finally loss of vision and changes in behavior. Whenever a pilot notices the first symptoms of hypoxia, he is expected to use additional oxygen. If oxygen is not available, he must make an emergency descent to a lower altitude.

To enable a pilot deprived of oxygen to know how much time he has for taking emergency measures, the **time of useful consciousness** is used. This is defined as the time during which the pilot can exercise judgment. The average time of useful consciousness decreases with altitude, as shown below:

Altitude in feet	*Time of useful consciousness*
15,000 to 18,000	30 minutes or more
22,000	5 to 10 minutes
25,000	3 to 5 minutes
35,000	30 to 60 seconds
45,000	9 to 15 seconds

A person affected by hypoxia tends to increase his breathing rate in an attempt to take in more oxygen. He may continue to gasp until **hyperventilation**, or overbreathing, occurs. Hyperventilation may also result from great emotional tension or anxiety, such as a pilot is likely to experience under the stresses of high altitude. As the pilot gasps for air, he "blows off" an excessive amount of carbon dioxide from the lungs and "washes out" carbon dioxide from the bloodstream. A certain level of carbon dioxide must be kept in the bloodstream at all times in order to signal the respiratory center in the brain to bring in more oxygen. When there is not enough carbon dioxide in the blood, the respiratory center in the brain ceases to function properly, and insufficient oxygen is brought into the blood.

With the loss of carbon dioxide from the blood caused by hyperventilation, the pilot usually experiences symptoms similar to those of hypoxia, such as dizziness, hot and cold sensations, and nausea. Finally he becomes unconscious. Aircraft accidents have been traced to unconsciousness caused by hyperventilation.

After the victim of hyperventilation becomes unconscious, he no longer gasps for air, and the condition tends to correct itself. As carbon dioxide accumulates in the blood and an adequate level of carbon dioxide is reached, the respiration center in the brain takes control of breathing once more. Normal breathing is resumed, and the victim regains consciousness.

Since the symptoms of hyperventilation and hypoxia overlap, a person who is hyperventilating is first treated for hypoxia by being given additional oxygen. If the symptoms do not disappear, he is urged to breathe more slowly until they do. These precautions are taken to prevent more serious effects from developing.

In addition to hypoxia and hyperventilation, the body may suffer from the mechanical effects produced by gases trapped in the body.

Trapped Gases

As the body ascends to altitude or drops from a higher to a lower altitude during flight, the free gases inside the body cavities expand or contract, following Boyle's law. Trouble develops when gases in the body cavities cannot escape or the air from the outside cannot enter. With **trapped gases** present, pressure builds up, and pain and sickness may result. Gases are most likely to become trapped in the ears, sinuses, teeth, stomach, and intestines.

EAR BLOCK.—The middle ear is the part of the ear that is affected most often by trapped gases during flight. To understand why this happens, you need to review the structure of the ear. The ear is composed of three sections: the outer ear, the middle ear, and the inner ear (Fig. 7). The **outer ear**, which includes the external auditory canal, ends at the eardrum. The eardrum, an extremely thin membrane (about 0.004 inch thick), marks the beginning of the **middle ear.** This part of the ear, located in the bones of the skull, contains three hinged bones that transmit vibrations from the eardrum to another drum separating the middle ear from the inner ear. The **inner ear** is the part of the ear that is responsible for hearing and body balance.

The middle ear connects with the back wall of the throat and the outside air through a short slit-like tube called the **eustachian tube.** As a person ascends or descends during flight, air must escape or be replenished through the eustachian tube to equalize the pressure in the cavity of the middle ear with that of the outside atmosphere. The adjustment is usually made automatically during ascent but has to be made consciously during descent. The eustachian tube allows air to pass outward with ease, but resists passage of air in the opposite direction. Air can usually be pushed through the eustachian tube during descent by swallowing, yawning, or tensing the muscles of the throat at intervals, thus causing the pressure of the air within the middle ear to equalize with that of the outside atmosphere. If passengers are asleep, they are awakened to allow them to swallow and ventilate their ears. An **ear block** may develop when descent is made

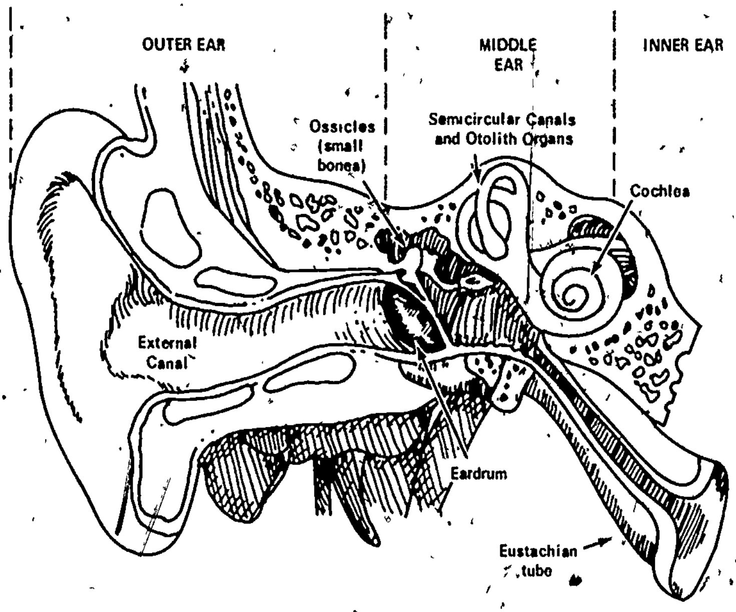

Figure 7. Parts of the ear. The outer ear and the middle ear are separated by the eardrum. The inner ear includes the balance-sensing organisms.

too quickly or when one is unable to equalize the pressure because the eustachian tube is swollen from a head cold or infection (Fig. 8). An ear block causes discomfort and pain.

When the inner ear threatens to become blocked during flight, all one has to do is close his mouth, hold his nose, and blow. This action forces air up the eustachian tube and into the middle ear. It ventilates the ears and is not dangerous. Nasal inhalants, such as Benzedrex, may also be helpful in clearing the ears if used properly.

SINUS BLOCK.—At altitude the sinuses may become blocked in much the same way that the middle ear does. A **sinus block** is treated in much the same way as an ear block. The sinuses are rigid bony cavities filled with air and lined with mucous membrane. There are four sets of sinuses (Fig. 9). Each of the sinuses connects with the nasal cavity by means of one or more small openings. Under normal conditions, the air can pass freely in and out of the sinus cavities, and pressure is equalized. If the ascent or descent is made too rapidly or if the openings to the

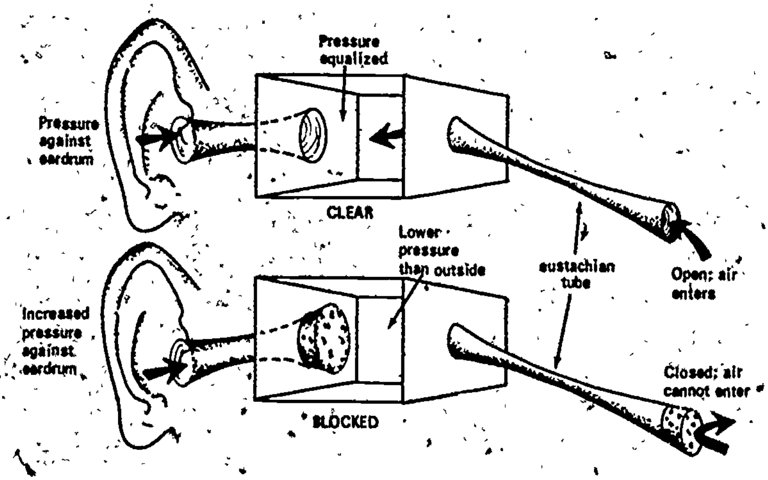

Figure 8. Middle ear showing ear block. The schematic diagram shows the middle ear as a box with an opening on either side. If air from the outside can enter the middle ear through the eustachian tube, pressure is equalized (above). If the eustachian tube is blocked, air is trapped in the middle ear (below).

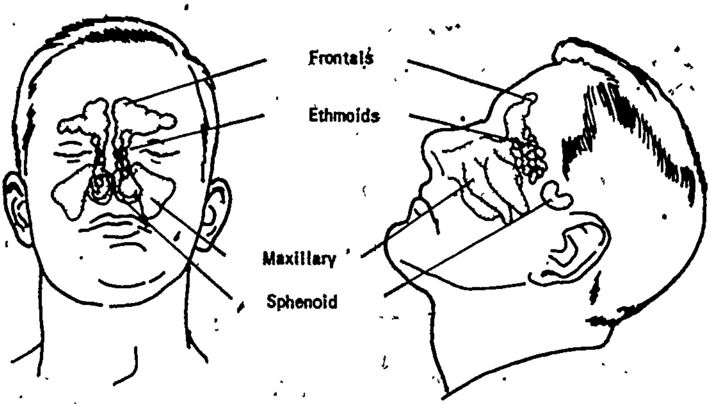

Figure 9. Four sets of sinuses. The frontal sinuses are the ones most often blocked during flight. Air trapped in the maxillary sinuses causes pain resembling a toothache.

sinuses are blocked because the mucous membrane is swollen, pressure builds upon within the sinuses, and pain results. The frontal sinuses are the ones most often blocked. Pressure in these sinuses causes a pain above the eyes, which may become severe. When the maxillary sinuses are affected, a pain develops in the upper jaw that is often mistaken for a toothache but is actually caused by trapped gases.

TOOTH PAIN.—Air does at times become trapped in cavities in the teeth or in the root canals, causing severe **tooth pain** at altitude. The only way to get relief is to descend from altitude. The toothache often disappears at the same altitude at which it was first observed on ascent. Gases may be trapped in the teeth at altitude in abscesses, imperfect fillings, and inadequately filled root canals. For this reason a flier has to keep his teeth in excellent condition.

GASES TRAPPED IN STOMACH AND INTESTINES.—Pain may also be caused by **gases trapped in the stomach and intestines,** but such gases usually do not become a problem until high altitudes are reached. In flights above 25,000 feet the expanding gases in the stomach and intestines may cause severe pain, lowering blood pressure and eventually bringing on shock. Relief can be secured before the danger point is reached by passing the gases. If this cannot be done, the only recourse is descent.

The gas trapped in the stomach and intestines is usually air that has been swallowed, but other gas, or flatus, may develop in the digestive process. Pilots who fly to high altitudes and astronauts are careful about the foods they select for their preflight meal, and during flight they eat foods that do not form gas in the stomach and intestines.

Other gases that cause problems in flight are those that have evolved, or changed from a liquid back to a gas. These gases cause decompression sickness.

Decompression Sickness

When the barometric pressure falls during ascent, the partial pressures of the gases in the body fluids decrease in proportion to the amount of that gas in the fluid, according to Henry's law, stated earlier. As a consequence, the gases that are in the highest degree of concentration begin to leave the body fluids and escape in the form of tiny bubbles, much as the gas escapes when a soft drink bottle is uncapped (Fig. 10). These escaping gases cause a number of disturbances known collectively as **decompression sickness.**

Since nitrogen is the gas found in the greatest proportion in the body, it is the first gas to come out of solution in the body as pressure decreases. Evolved nitrogen causes the bends, the chokes, and other forms of decompression sickness. These conditions usually are not produced at altitudes below 30,000 feet, but decompression sickness has been known to occur at altitudes as low as 18,000 feet.

BENDS.—Upon ascent to high altitudes a pilot may develop **bends,** a form of decompression sickness that also affects deep-sea divers when they ascend too quickly. The condition is characterized by pains in and about the joints. At first the pain may be mild, but it usually is progressive and may become extremely severe and even crippling upon reaching very high altitudes. The pain may spread from the joints to the entire arm or leg. Joints such as those of the knee and shoulder are most frequently affected. The pain may be lessened by keeping the affected part immobile.

CHOKES.—Another form of decompression sickness brought about by evolved gases is known as the **chokes.** This condition is characterized by pain in the chest. The pain is probably brought about by the pressure of tiny gas bubbles that block the smaller blood vessels of the lungs. At first the pressure is felt as a deep burning sensation, but gradually it becomes a severe stabbing pain, which is aggravated by deep breathing.

OTHER KINDS OF DECOMPRESSION SICKNESS.—The nitrogen bubbles released into the body may also cause disturbances of the skin or of the central nervous system. When the central nervous system is affected, the symptoms may be similar to those of hypoxia.

TREATMENT OF DECOMPRESSION SICKNESS.—As decompression sickness becomes more severe, the pain caused by the escaped gas bubbles becomes more intense, and faintness, dizziness, and nausea may result. The victim finally goes into shock and becomes unconscious. Relief can be obtained only be descending. Treatment should be given as soon as possible after the victim has reached the ground.

The Air Force has special chambers, like the one shown in Figure 11, for treating the victims of decompression sickness. The patient is transported to the chamber in an aircraft specially pressurized to sea-level pressure. In the chamber, pressure is applied to the patient's body to force the escaped gas bubbles to go back into solution again, and the pain is relieved. The patient

Figure 10. Bends caused by nitrogen bubbles. The flier's body might be compared with a bottle of soda pop. At very high altitudes the nitrogen dissolved in the body fluids may come out of solution and cause severe pain of the joints, or bends.

breathes pure oxygen and is treated for shock. Emergency treatment for decompression sickness may be necessary if the seal of a pressurized cabin is broken at high altitude.

RAPID DECOMPRESSION

Occasionally an aircraft cabin decompresses, or loses pressure, during flight. When there is **rapid decompression** at a high altitude, there is an explosion as the pressure suddenly decreases. The occupants of the cabin are then exposed to all the danger of the rarefied atmosphere noted previously plus extremely low temperatures, flying debris, and possibly windblast.

If the aircraft or spacecraft were flying at 63,000 feet or above, there would be an additional hazard. The blood and other body fluids boil if exposed to the ambient atmosphere at this level. To understand why this happens, it is necessary to keep in mind facts concerning the following. (1) evaporation and the boiling point of water as related to the ambient atmosphere, (2) the temperature of the human body and the abundance of fluids in the body, and (3) the boiling point of water at 63,000 feet.

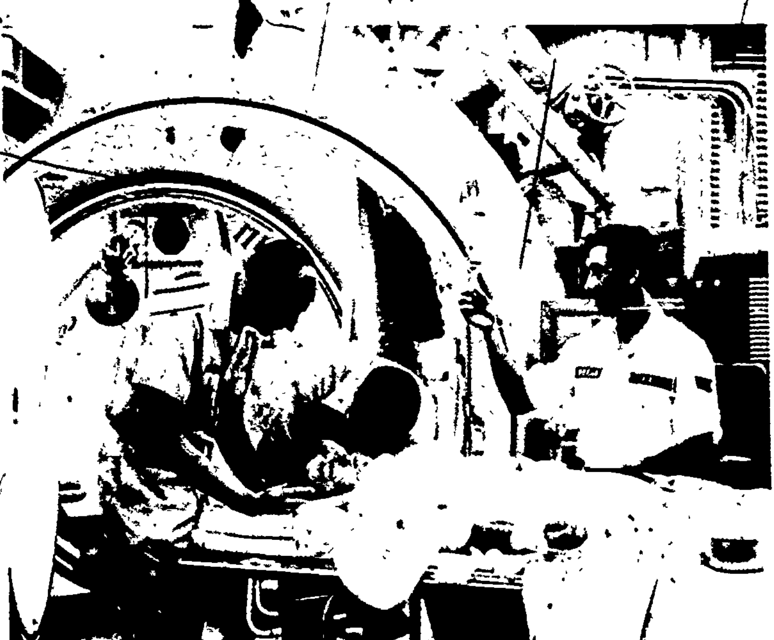

Figure 11. Chamber for treatment of decompression sickness. The patient will be subjected to pressure in the chamber. This should cause the nitrogen bubbles to go back into solution and bring the body back to normal.

You are familiar with the fact that water boils at a temperature of 212 degrees F. at sea level, where the pressure of the ambient air is 14.7 psi. As more heat is applied to the water, bubbles and steam form, and the temperature of the boiling water remains at 212 degrees F. As one goes up into the mountains, the barometric pressure falls, and the boiling point of water decreases. In the boiling process at higher altitudes, evaporation takes place at a lower temperature. Now consider that the human body, through its respiratory and circulatory systems, takes in oxygen to burn food and produce heat. The human body contains blood and other fluids that are largely water. The body keeps these fluids at a temperature of about 98.6 degrees F. Since the boiling point of water decreases with altitude, a point is finally reached at which the boiling point of water (and body fluids) becomes 98.6 degrees F. This point is reached at an altitude of 63,000 feet. At this level the body fluids boil (Fig. 12). Subsonic jet transports do not fly above 63,000 feet except in an emergency. Only military pilots and astronauts now fly at such high altitudes.

If a space cabin undergoes rapid decompression at levels below 63,000 feet, the chief danger is from hypoxia, or lack of oxygen. Studies have shown that a normal healthy person can survive relatively severe decompression without harm to the body if the air passages in the lungs remain open. In case of decompression, the pilot's first thought is to obtain oxygen and then bring the aircraft down as quickly as possible. The time of useful consciousness may be reduced to one-half or one-third the normal time if the decompression has been rapid and the air has been forced out of the lungs due to rapid expansion.

PRINCIPLES AND PROBLEMS OF VISION

Of all man's sensory equipment none is more important to him in flying than his eyes. A pilot must be able to see well so that he can judge speed and distances, enabling him to take off and land safely and prevent collisions in midair. In addition, he must be able to distinguish colors so that he can interpret signal flares and beacons, and he must have good night vision so that he can fly safely in the darkness. Even when visibility is zero, vision is still important, since the pilot must be able to read his instruments, charts, and maps.

Because good vision is essential to the pilot, high standards of visual acuity are set. It is important, however, that a pilot not only has a good pair of eyes but also trains himself to use his eyes. Since he has fewer visual cues in the air than on the ground, a pilot must learn to observe, interpret accurately what he sees, and keep from being misled by visual illusions. To understand the problems of vision that face pilots and astronauts, it is necessary to know something about the basic structure of the eye and its physiology.

Figure 12. Fluid boiling at simulated high altitude. This pilot is protected in his pressure suit. Otherwise his blood would boil.

Structure and Physiology of the Eye

The eye is like a camera with an almost inexhaustible supply of film. Both the eye and a camera have a shutter, a diaphragm, lens, and a method of focusing, all arranged in an opaque light-tight container.

Objects that reflect or emit light project an image of themselves on the retina of the eye. The **retina** is an interior coating of the eye located around the sides and to the back. It contains light-sensitive cells known as cones and rods (Fig. 13). These are connected to the optic nerve, which transmits messages directly to the brain. We have one blind spot located where the optic nerve enters the eye. A person does not usually notice this, since the visual fields of both eyes overlap and, in effect, eliminate this blind spot. The way the cones and rods are distributed in the retina affects the way we see during daylight and

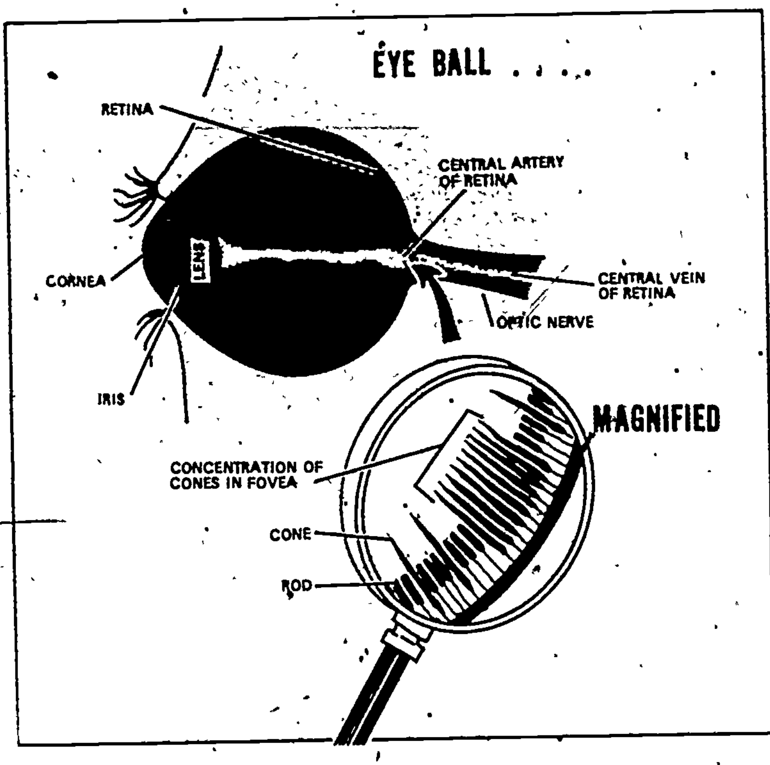

Figure 13. Cross section of eyeball and retina with detail of cones and rods. The cones are concentrated at the center of the retina, the rods at the outer portions. In between there are both cones and rods.

at night. Experiments have shown that the cones are used mainly in day vision and the rods in night vision.

The greatest concentration of cones is in the center portion of the retina in a slight depression known as the fovea. There are many cones in the eye, and they excite the interconnecting nerve cells on a one-to-one basis. This is the reason why the cones are able to detect fine detail. They are also sensitive to color.

The rods are found primarily in the outer portions, or the periphery, of the retina. There is also a zone between this area and the fovea, or center, that is occupied by both rods and cones. Rods are less numerous than the cones. The rods are not sensitive to color, and they do not detect light in wavelengths greater than red. Rods are very valuable to us, however, because they are much more sensitive to light than cones are. They can be activated by an amount of light equal to starlight on a clear night. The cones must have light equal to at least half the intensity of moonlight in order to function.

Night Vision and Dark Adaptation

Because there are no rods in the center of the retina, or the fovea, an object cannot be seen at night under low light conditions (less than one-half moon illumination) when one looks directly at it. For this reason a pilot learns to look at objects in the darkness by glancing slightly to one side or other of the object so that the image will fall on the rods in the retina. This technique is called **off-center vision**, or scanning, and it can be developed with practice.

Rods are not always instantly ready for use. You may have made this observation for yourself when you went immediately from the bright daylight into a darkened movie theater or from a brightly lighted room to the dark outdoors at night. At first you could see nothing in the darkness. Then, after several minutes, you began to see dim forms and large outlines. The time required for **dark adaptation** varies from person to person. The average time required is 30 minutes.

To shorten the time required for dark adaptation, pilots may wear goggles with red lenses. The rods are more sensitive to purple and blue and the colors of shorter wavelength than red. The rods are affected so little by the red light that the red goggles allow a pilot to keep a certain amount of dark adaptation even in a brightly lighted room. The red goggles also decrease the effects of accidental exposure to light as the pilot goes from the ready room to the waiting aircraft.

Ever since World War II red light has been used traditionally for lighting the cockpits and instruments of aircraft to keep the pilot from losing dark adaptation at night. Such lighting retains the sensitivity of the rods as much as possible and allows some light for the cones of the fovea to function. Now, with the increasing use of electronic devices for navigation, some engineers are recommending the use of low-intensity white light for illuminating the cockpit at night. Such light would allow the pilot to see the true colors of instruments and would not disturb his dark adaptation too much.

Factors Affecting Visibility

Besides the adaptation of the retina, many other factors determine the **visibility** of an object, or its ability to be seen. Some of these factors are the angular size of the object, the amount of illumination on the object, the contrast between the object and its background, the length of time the object is seen, and the condition of the atmosphere between the observer and the object. In general, the visibility of an object increases with an increase in its angular size and an increase in the amount of illumination, contrast, time of viewing, and the clarity of the atmosphere. Insofar as he is able, the pilot tries to improve the conditions of visibility, and the engineers assist him by the way they design the aircraft and the signal lights and approaches at the airport. The windshield and the windows of aircraft are made of materials that reduce glare and allow the light to penetrate.

As the pilot takes his aircraft to higher altitudes, the ambient supply of oxygen decreases. This reduces visual acuity, as well as the ability to adapt the eyes to darkness. With an increase in altitude the visual surroundings change also. There is less haze, the sky becomes darker, and the sun's rays become more intense and have a higher proportion of ultraviolet light in them. As a protection against the bright sunlight, pilots who fly at high altitudes wear sunglasses, and astronauts have gold-plated visors in their space helmets to protect them against the glare. To prevent the cockpit of high flying aicraft from having dark shadows and glare, they are illuminated with a white light during the daytime.

Although visibility increases with the time an object is viewed, a pilot avoids staring at objects. Instead he spots or scans an object, looking at it repeatedly but for no more than a second at a time. If he were to stare at objects, especially moving lights at night, he might have a **visual illusion**. An illusion is a false sensory impression or a true impression that is not interpreted correctly.

Visual illusions are a hazard to a pilot, who must maintain his sense of distance and orientation in the air.

SPATIAL DISORIENTATION AND MOTION SICKNESS

It is much more difficult for man to orient himself in flight than on the surface of the earth. Since he can move freely in three directions during flight, he sometimes finds it difficult to sense the direction in which he is moving and the relation of one position to another. When a pilot cannot see the horizon clearly, he may not know which direction is up or down. In such cases a pilot undergoes **spatial disorientation.** The problem of keeping oriented is even more difficult for the astronaut in deep space. All the astronaut can see from his spacecraft window is a maze of stars against a black background unless he can spot the moon, the earth, or another module of his spacecraft, which might tell him something about his position.

Sensory Equipment for Orientation

For the pilot, sight is the most reliable means of determining position. Since the pilot has few visual cues in the air, it is important that he use those cues he has to keep himself accurately oriented. When a pilot brings his aircraft out of a bank or turn, for example, he regains his orientation by following familiar objects on the ground and thus establishes the true horizon. When he checks his observations against his instruments, the pilot again makes use of sight. When the astronauts make their "walks" in space outside their spacecraft, they can orient themselves by looking steadily at their spacecraft.

Besides using (1) vision, man makes use of two other kinds of sensory equipment to orient himself during flight. (2) the **sense of balance in the inner ear,** and (3) the **muscle sense,** or posture sense, derived from sensors in the muscles and bones. Very little is known about the actual working of this third kind of balance sense, but its effects can be felt by anyone. It is felt as a sense of pressure, such as one feels on the feet when standing or on the seat when sitting. Pilots used this sense of orientation when they flew "by the seat of the pants." In low-flying aircraft, pilots still make use of the muscle sense, but in high-performance aircraft pilots make more use of vision and the balance sense in the inner ear. The principles and problems of vision have already been explained. Here we are concerned mainly with the second orientation sense, that found in the inner ear.

Balance Organs in Inner Ear

The inner ear is important both for hearing and for sensing balance. The pilot is concerned principally with the second function, that of sensing balance. He learns about the way the balance-sensing organs in the inner ear work so that he can understand why he may misinterpret the signals sent to his brain, causing spatial disorientation and motion sickness, or nausea caused by motion. The organs of balance in the inner ear (Fig. 14) consist of (1) the three semicircular canals, each located in a different plane, and (2) two sacs at the base of the canals called the **otolith organs** because they contain many minute particles known as otoliths, or "ear dust."

The semicircular canals sense the beginning and ending of rotation or turns (partial rotation). The otolith organs sense the speeding up or slowing down of motion in a straight line. Together the two kinds of balance organs in the inner ear sense all kinds of motion. During the course of ordinary movements on the ground, they sense accurately and send true messages to the brain. For example, they sense leaning, stooping, bending, running, and walking, and the direction in which the motion is taking place.

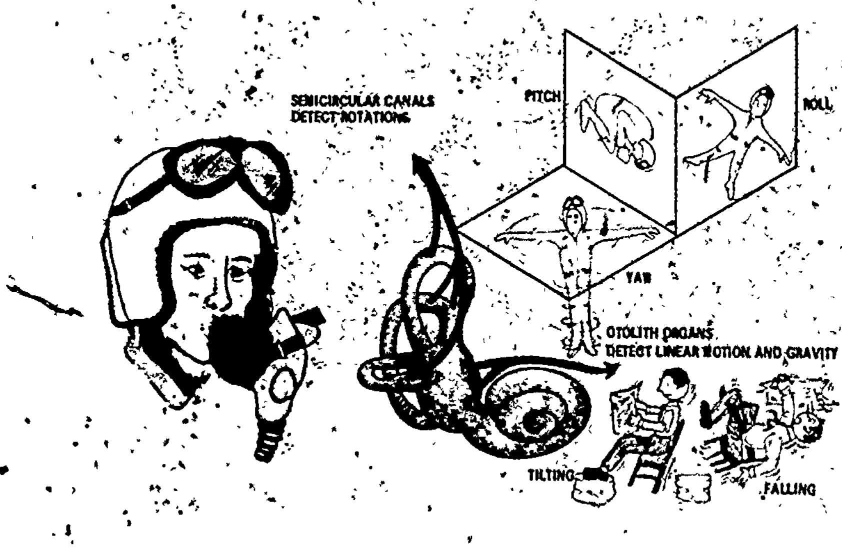

Figure 14. Balance organs in inner ear. The semicircular canals and the otolith organs together sense balance and direction of movement. Each of the three semicircular canals is located in a different plane. The two otolith organs are located at the base of the semicircular canals.

If your body has been spun rapidly or you have taken a ride on a roller coaster, you may suffer from motion sickness. Similarly, a pilot who is subjected to prolonged or severe acceleration may experience spatial disorientation and motion sickness. His condition is brought about because the balance mechanisms in his inner ear have been affected by inertia. As a result, the hair filaments do not sense the movement of the fluid in the semicircular canals in the normal way (Fig. 15). Also, because of inertia, the otoliths ("ear dust") do not register motion in the usual way (Fig. 16).

To remain oriented in flight, a pilot checks the messages sent to his brain by the balance organs in his inner ear against his vision and his muscle sense of balance. He checks all three kinds of balance sensing against his instruments. He does this whenever he flies using visual flight rules. When visual cues are no longer adequate, the pilot goes on instruments. He must then trust his instruments completely and ignore the signals his inner ear is sending to his brain. If a pilot insists that his sensations are accurate and that his instruments have somehow gone wrong, he is in trouble. Pilots have to accustom themselves to flying on instruments.

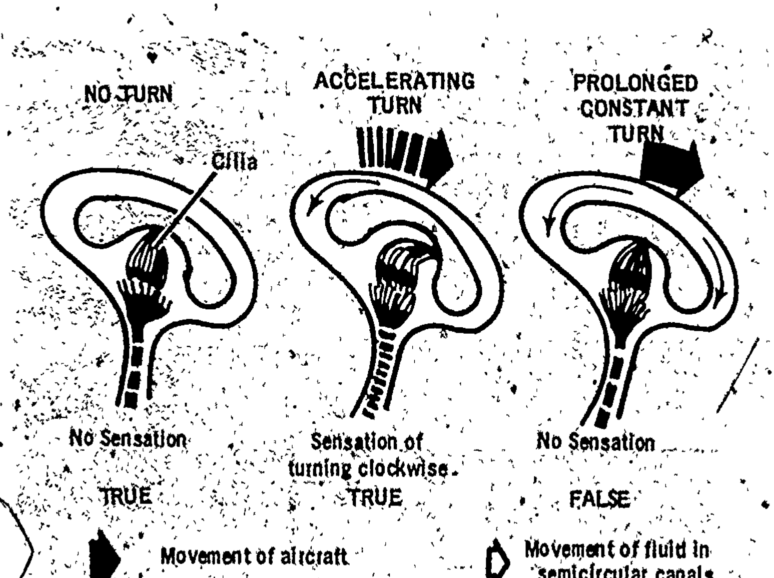

Figure 15. Semicircular canal affected by inertia. Each semicircular canal is filled with a fluid. The fluid moves as the body or aircraft rotates and causes the cilia (hair cells) to bend. The hair cells are connected with nerve endings that report the sensation to the brain.

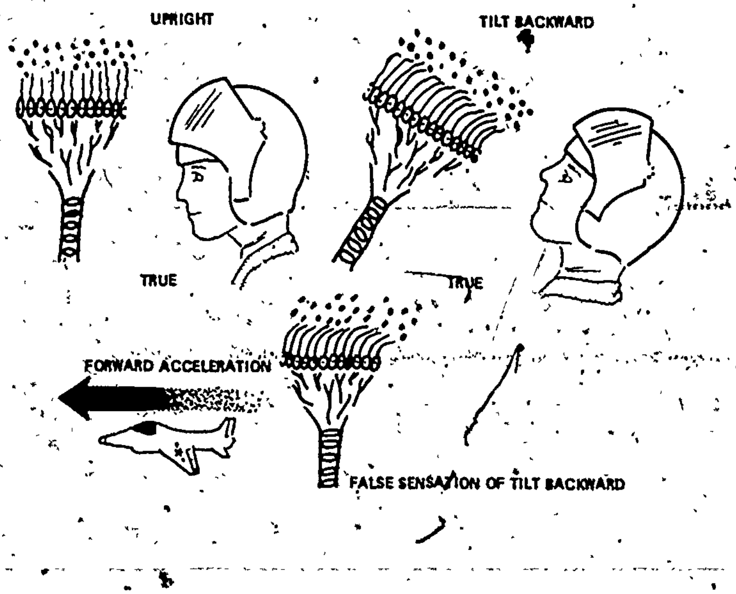

Figure 16. Otolith organ affected by inertia. As the head or the aircraft moves, the otoliths move and cause the hair cells to bend. The hair cells are connected with nerve endings that report the sensation to the brain.

ACCELERATION AND DECELERATION: INCREASED G-FORCES

Although the effects of acceleration and deceleration during commercial flights may cause some passengers to experience disorientation and motion sickness, these effects are not prolonged and severe enough to be classed as flight stresses. When military pilots maneuver or when astronauts are launched or recovered, however, they may be subjected to severe stress from the effects of **acceleration** and **deceleration.**

Speed in itself does not harm the body. In your location on the earth you are revolving around the sun at an average speed of 64,800 mph, but you are unharmed. In fact, you have no feeling that the earth is moving. Stresses on the body occur only as a result of the forces which produce acceleration or deceleration. You experience these forces, in a mild form, when an automobile starts or stops suddenly and either throws you back against the seat or forward toward the dashboard. In flight, these forces may be excessive and prolonged. When the body is subjected to large amounts of acceleration or deceleration during flight, the stresses are felt as increases in weight, or gravity force, or what are known as increased **G-forces.**

On the ground it is a simple matter to compute G-force. Under normal conditions it is a force of 1 G (one earth gravity force) exerted upon the body and acting in a direction toward the center of the earth. In flight the G-forces might be exerted in different directions, depending upon the kind of bank, turn, or spin. In flight the G-forces may increase greatly; and they may act in any direction on the body. The principal kinds of increased G-forces in flight are the positive and negative G-forces. A **positive G-force** acts from head to foot, just as the normal gravity force does when a man is in a standing position on the ground (Fig. 17). A **negative G-force** acts from foot to head, or as gravity would act upon a man standing on his head. A negative G-force occurs only rarely, such as when the aircraft makes a nose-over.

Under a positive 4 G-force, a seated pilot who weighs 150 pounds on the ground would weigh 600 pounds. He would be pulled down into the seat, his arms and legs would feel like lead, his cheeks would sag, and he would be incapable of any free body movement. At 5 G a seated pilot is likely to black out. The effects of increased G-forces on the body vary greatly from one person to another, however. They also vary according to the rate or amount of the force, the length of time the force is sustained, and the direction in which the force is exerted on the body.

Research has shown that there are three principal ways of counteracting excessive G-forces: (1) train the pilot to cope with these forces, (2) change the position of the pilot in the flight machine so that the G-forces act across the trunk of the body (are transverse rather than positive or negative), and (3) equip the pilot with a G-suit (described in Chapter 3). All three methods are used in spaceflight, but only the first and third methods are used in aviation.

NOISE AND VIBRATION

Increased G-forces may present serious flight stresses only for military pilots and for astronauts, but all pilots are subjected to noise and vibration. Recent studies by the National Aeronautics and Space Administration (NASA) have identified noise as the number one problem of civil aviation. This includes both the noises that affect the pilot and crew in the aircraft and the community near the airport. Noise and vibration probably cause fliers more inconvenience and annoyance than any other factor in flight. Both undoubtedly have an important part in producing headaches, visual and auditory fatigue, airsickness, and the general discomfort experienced at the end of a long flight. Of greater concern is the fact that constant exposure to loud noises may cause permanent damage to a flier's ears.

The unit of sound intensity, or loudness, is the **decibel** (db). The decibel scale is a relative one, expressing how much greater one sound intensity is than another. In common usage the noise level is referred to as being of so many decibels, but the ear senses sound not only by its intensity but also by audiowave frequency. Sound frequency is measured in cycles per second (cps). Two sounds of the same intensity and frequency are sensed as being

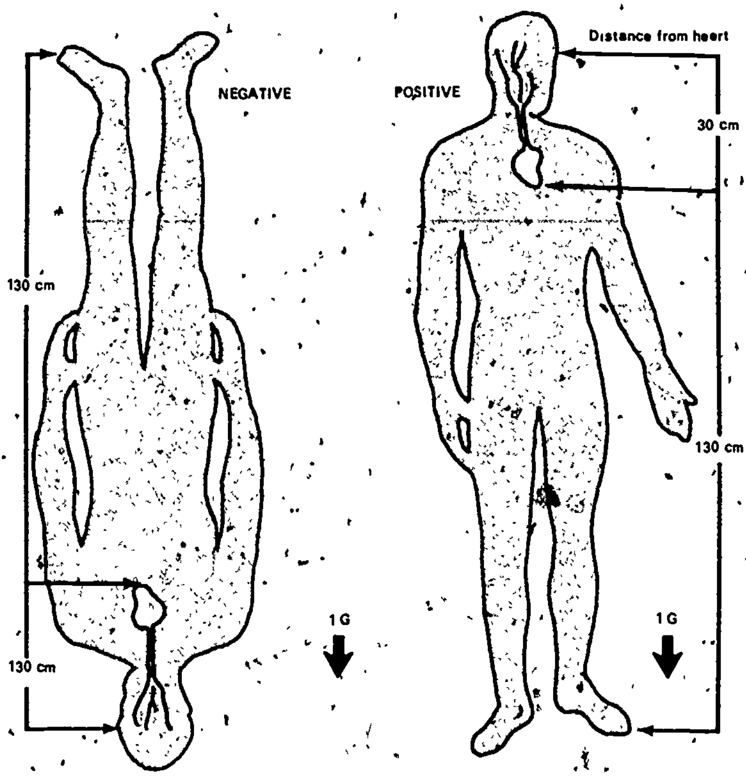

Figure 17. Positive and negative G forces. The body is filled with blood and other fluids that act like a column of static water. Pressure is greatest at the bottom of the column of fluids. If the G force is positive, pressure is greatest at the feet, if negative, at the head. The crucial part of the blood column is that between the heart and the brain and eyes. This part is about 30 cm (about 12 inches) high.

equally loud. Two sounds of the same intensity but of different frequencies are sensed by the ear as being of different loudness.

Both propeller-driven and jet aircraft produce noise of high intensity. Propeller-driven aircraft produce high noise levels in the low-frequency range and jet aircraft in the high-frequency range Most of the noise from aircraft originates in the engines. Jet aircraft that break through the sound barrier also produce a loud sonic boom, but the pilot does not hear this.

With spacecraft, as with aircraft, most noise originates in the engines. Astronauts are not subjected to aerodynamic noise in orbit, as there is no atmosphere to produce shock waves or carry sound. The noises heard inside the spacecraft in orbit are those produced when a large rocket thruster is fired to change orbit or small jet thrusters are fired to stabilize the spacecraft in orbit. Up to the present time no significant amount of noise has been observed upon reentry, but noise levels are extremely high at launch, when the giant rocket engines of the booster are fired.

The safe level of noise for a pilot or astronaut varies with the individual, and the frequency of the noise, as well as its intensity, must be taken into consideration. For any given individual, the longer the time he is exposed to a noise and the more intense it is, the greater will be the danger of damage to the ears. Noise levels of 130 decibels or above are dangerous (Fig. 18), and no one should be exposed to them without some kind of protection in the form of ear muffs or ear plugs. Noise levels of 145 to 150 decibels mark the limits of man's tolerance. A person exposed to sound at these levels for only about a minute would suffer permanent damage to his hearing mechanism.

Vibrations are measured in frequencies. Vibrations are side-to-side and up-and-down motions. The usual source of vibration in aircraft and spacecraft is the power plant itself. The design of the aircraft or space booster may contribute to the vibration, but the pilot or astronaut can do nothing about this once the vehicle is built.

One of the effects of vibration in aircraft is to blur the vision. Such blurring may be experienced by pilots subjected to buffeting as they take the aircraft through the sound barrier. In aircraft traveling at subsonic speeds the principal effect of vibration is to cause fatigue and irritability, but it is possible that the pilot may become hypnotized as a result of rhythmic monotonous vibration.

Noise and vibration decrease the pilot's efficiency. Extremes of heat and cold also affect efficiency.

HEAT AND COLD DURING FLIGHT

When aircraft first began to fly at higher altitudes, one of the big problems was to protect aircrews against the frigid temperatures. Now cold at altitude is a problem only for the smaller, slower aircraft that fly at what are now considered the lower altitudes. High-performance aircraft have pressurized cabins with controlled heating and cooling.

With high-performance aircraft and with spacecraft the main problem is the reverse: to dissipate heat and keep the cabin comfortable. Within a closed cabin, heat builds up as it is given off by the human body and the power systems. The largest amount of

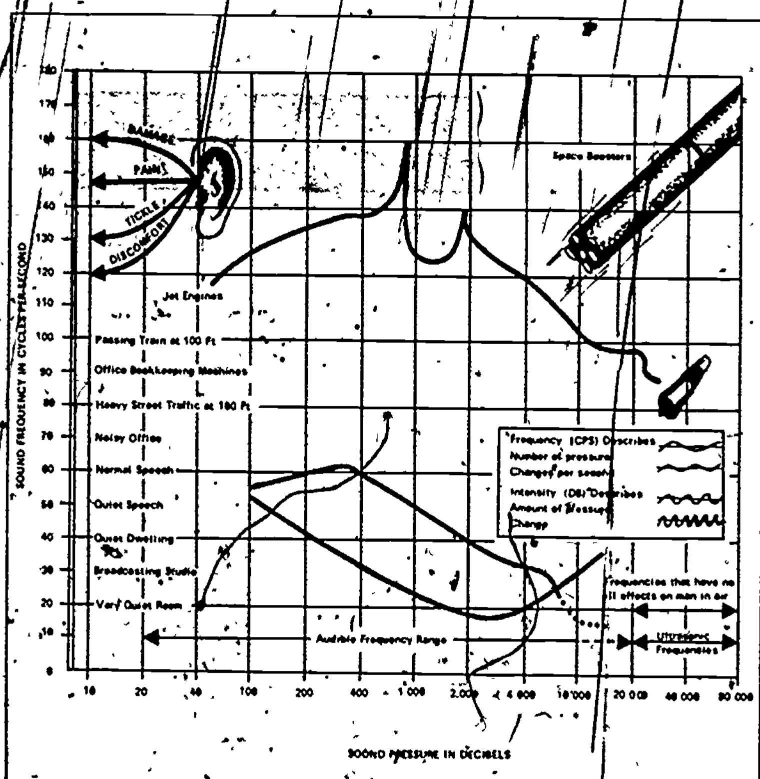

Figure 18. Noise produced by jet and rocket engines. The pressure or intensity of the noise is expressed in decibels, the frequency in cycles per second. Note how this noise compares with more familiar kinds of noise.

heat, however, is generated on the skin of the aircraft or spacecraft as it travels at high speeds through the atmosphere. An aircraft that is flying at a speed twice that of sound has skin temperatures increased by about 400 degrees F. as a result of **aerodynamic heating.** The Apollo command module, as it reentered the atmosphere upon return from the moon, reached a searing 5,000 degrees F. Flames burst around the module, and it would have been completely burned up if it had not been for ablation cooling, or cooling by melting of surface materials from the heat shield. The cabin inside a spacecraft is cooled by air-conditioning equipment, much as the cabin of a high-performance aircraft is.

To keep man comfortable within an inclosed cabin or cockpit, engineers have designed systems to keep temperatures at 70 to 75 degrees F. and to control the humidity. The human body, a heat-producing machine, maintains internal temperatures at about 98.6 degrees F. and skin temperatures at about 92 degrees F. Man helps to regulate the temperature of his body by the kind of flight clothing he wears. If the environmental control system and the clothing do not keep the body at comfortable temperatures, the body itself makes an adjustment through such processes as shivering, perspiring, and enlarging the blood vessels to bring more blood close to the surface of the skin. Under the most severe stress of heat and cold the internal temperature of the body does not change markedly.

Since cooling and heating systems in unpressurized aircraft are still affected by the temperature of the surrounding air and since aircraft and spacecraft cabins may undergo decompression, flight physiologists are interested in knowing about the temperatures that might be expected at different levels of the atmosphere, as described earlier. As the surrounding temperature begins to vary from the ideal, man experiences discomfort, and efficiency drops off rapidly.

There are two dangers associated with exposure of the body to the cold. The most immediate danger is frostbite on hands, feet, face, and ears. **Frostbite** is the actual freezing of fluids in the body tissues. The second danger is that continued exposure to low temperature will reduce efficiency to the point where safe operation of the aircraft or spacecraft is impossible. The temperature at which the cold seriously interferes with efficiency depends upon other factors in addition to temperature, such as air circulation, length of time exposed, clothing, and general physical condition.

At temperatures over 85 degrees F., discomfort, irritability, and loss of efficiency are pronounced. High temperatures also reduce ability to cope with other stresses, such as increased G-forces and hypoxia.

Although the stress resulting from heat and cold may cause loss of efficiency, a pilot is not often placed in danger from such stress. Noxious gases and vapors, on the other hand, cause loss of efficiency and quickly become a threat to survival.

NOXIOUS GASES AND VAPORS

Inside an inclosed cabin, **noxious gases and vapors**, or gases and vapors that harm the body, may accumulate. In aircraft cabins that are not completely closed the problem is not a serious one. In such aircraft the air pumped in from the outside and compressed is constantly dumped overboard at a high rate, carrying with it harmful gases and vapors, such as carbon monoxide. In aircraft that fly above 50,000 feet and in spacecraft, however, the cabin is completely closed. In this kind of cabin there can be no wasteful changing of the breathing atmosphere in order to keep it pure. The atmosphere must be recirculated and reused over and over again. Maintaining a pure breathing atmosphere is especially important in spacecraft, as astronauts must remain in the spacecraft for extended periods. In spacecraft there is an environmental control system for cleaning and deodorizing the atmosphere and removing toxic materials from it.

An aircraft or spacecraft cabin is not likely to become contaminated from the liquid oxygen (LOX) or compressed oxygen carried on board to supply the breathing atmosphere or from the equipment itself. The oxygen is carefully inspected, and all equipment for supplying an artificial atmosphere is tested on the ground before being used in flight. The breathing atmosphere can easily become contaminated from inside sources, however, if care is not used. The atmosphere may receive harmful gases and vapors from such sources as the byproducts of human respiration and body wastes and from exhaust gases, fire extinguishers, fuels, hydraulic fluid, and antiicing fluid. Probably the most serious contaminants are carbon monoxide and carbon dioxide.

Carbon monoxide is the colorless, odorless, and tasteless gas that has caused deaths when automobile engines were left running in closed garages. Aircraft engines may also give off carbon monoxide, and it is found in cigar and cigarette smoke. When carbon monoxide is inhaled, it passes into the lungs through the alveolar walls into the bloodstream. The red blood cells absorb carbon monoxide 200 to 300 times more readily than they do oxygen. For this reason only a small amount of carbon monoxide in the atmosphere may be fatal. In Air Force aircraft the allowable amount of carbon monoxide is only 0.005 percent, or 50 parts per million. As little as 0.02 percent of carbon monoxide in the breathing atmosphere, or 200 parts per million, can cause headaches, and 0.16 percent may cause death in two hours.

If the air within an inclosed cabin is not purified, **carbon dioxide** soon accumulates from human breathing. At sea level the body begins to react to concentrations of carbon dioxide as low as 1 percent, the amount of reaction depending upon the time of exposure. Concentrations of 7 to 10 percent carbon dioxide can cause impairment of vision and hearing, as well as affecting respiration. Concentrations above 10 percent result in loss of consciousness and death. As the altitude increases, smaller concentrations of carbon dioxide become harmful and finally lethal.

In the spacecraft carbon dioxide is filtered out, and the breathing atmosphere is recycled into pure oxygen. In aircraft, sufficient oxygen supplies can be carried on board, and recycling is not necessary. In aircraft the pilot may have instruments for measuring the purity of the atmosphere. If he suspects that contaminants are present that cannot be detected with the instruments he has, he submits samples of the atmosphere for testing (Fig. 19).

In addition to the stresses that are normally imposed on the human body during flight, man imposes other stresses upon himself.

SELF-IMPOSED STRESSES

For the pilot, self-imposed stresses include all the things that he does that he should not do, or neglects that he should do. Self-imposed stresses include excessive or unwise use of drugs, alcohol, or tobacco, or neglecting to get enough rest and exercise, or failing to eat the right kinds and amounts of food. Self-imposed stresses are not a problem with astronauts, as they are even more carefully screened than pilots are, and they are isolated before liftoff. No astronaut is allowed to fly if there is any danger of indisposition during flight.

Like the astronauts, most pilots learn to discipline themselves and follow a careful program of good diet, exercise, and rest, and they abstain from alcoholic beverages before flight time. A rule of thumb for pilots is that there must be "eight hours between the bottle and the throttle." Sometimes, however, pilots do not realize how much self-imposed stress may result from only one drink or from taking ordinary over-the-counter medications like aspirin. Practices that cause no apparent harm to the body on the ground may place stresses on the body at altitude because

Figure 19. Chamber used for studying contaminants in aircraft cabins. This chamber is located at the Air Force School of Aerospace Medicine at Brooks AFB, Texas.

they interfere with the intake of oxygen. The most significant sources of self-imposed stresses are alcohol, tobacco, and drugs.

Alcohol

The effect of an alcoholic drink is magnified at altitude. Even at the relatively low levels of 10,000 to 12,000 feet, a pilot would show a falling off in his performance if he took one drink. One drink at 10,000 feet can have the same effect as two or three drinks at sea level. A pilot cannot afford even a small decrease in efficiency. He has to keep his mind clear and his judgment keen to make important decisions instantly, and he must be able to speak distinctly and hear well to communicate with ground control.

Tobacco

Cigarettes contain harmful nicotine, and the deadly carbon monoxide makes up 2.5 percent of the volume of cigarette smoke and more of the cigar smoke. If the smoke of three cigarettes is inhaled at sea level, a blood saturation of 4 percent carbon monoxide may result. This will reduce ability to see clearly and ability to adapt one's eyes to the dark at sea level to the same extent as in a person experiencing mild hypoxia at 8,000 feet. Smoking at 10,000 feet produces effects equivalent to those experienced at 14,000 feet without smoking. The effects of smoking at higher altitudes are even more harmful. With heavy smoking, blood saturation with 8 percent carbon monoxide may result. This causes a corresponding drop in the amount of oxygen in the blood, which leads to hypoxia.

Drugs

Aspirin is probably the most frequently used drug sold over the counter. It causes no toxic effects when used in moderation on the ground and could be used safely during flight. If used excessively at altitude, however, it could interfere with absorption of oxygen by the blood and cause problems. Even nasal decongestants, if used excessively, can cause self-imposed stresses at altitude. No tranquilizers or sedatives should be used by pilots before flight. They would cause dizziness and dulling of judgment at altitude. If a pilot needs medication, he probably is not fit to fly and should consult his doctor.

As the human body is subjected to self-imposed stresses, as well as the ordinary stresses of flight, it reacts to keep the cells and tissues in the same condition as at sea level. As man has progressed in flight through the atmosphere and into space, he has learned more about countering flight stresses. He has done this through the professions of aerospace medicine and human engineering.

TERMS TO REMEMBER

oxygen
nitrogen
troposphere
stratosphere
ionosphere
exosphere
physiological zone
physiological-deficient zone
partial space-equivalent zone
total space-equivalent zone
respiration
bronchi (bronchial tubes)

alveolus (pl., alveoli)
thorax
diaphragm
respiration cycle
inhalation
exhalation
atria
ventricles
hypoxia
time of useful consciousness
hyperventilation
trapped gases
outer ear
middle ear
inner ear
eustachian (yew STAY shen) tube
ear block
sinus block
tooth pain
gases trapped in stomach and intestines
decompression sickness
bends
chokes
rapid decompression
vision
retina
cones
rods
off-center vision
dark adaptation
visibility
visual illusion
spatial disorientation
motion sickness
sense of balance in inner ear
muscle sense of balance
semicircular canals
otolith organs
acceleration
deceleration
G-forces
positive G-force
negative G-force
noise level
decibel
vibrations
aerodynamic heating
frostbite
noxious gases and vapors
carbon monoxide
carbon dioxide

LAWS OF GASES

Boyle's law
Dalton's law
Henry's law

QUESTIONS

1. What are the two layers of the atmosphere in which aircraft fly? The three physiological divisions in which aircraft fly?

2. What is Dalton's law? How does this law determine the oxygen pressure required for the breathing atmosphere of the spacecraft and the space suit?

3. How are the respiratory and circulatory systems affected by flight to higher altitudes?

4. What causes hypoxia? What causes hyperventilation? Why is hypoxia especially dangerous?

5. What is meant by the time of useful consciousness? How is it affected by altitude?

6. What is meant by an ear block? How can it be prevented?

7. Where are gases most likely to become trapped in the body at altitude?

8. What is meant by decompression sickness? What are some forms of decompression sickness?

9. Why is good vision especially important to a flier? Why is a flier liable to be affected by visual illusions?

10. What part of the flier's eye functions in day vision? in night vision? Why have aircraft cabins been traditionally illuminated with a red light at night?

11. What three means does a pilot use to maintain balance and orient himself during flight? What causes disorientation during flight?

12. What is meant by the G-forces? What causes increased G-forces during flight?

13. How do excessive noise and vibration harm the pilot?

14. Does excessive heat or excessive cold present the greater problem in the flight of modern high-performance aircraft? Why?

15. What harmful gases are most apt to build up in an aircraft cabin?

16. What is meant by self-imposed stresses? Can these present a serious danger to the pilot?

THINGS TO DO

1. With the help of your biology teacher, work out an experiment on decreased atmospheric pressure with increased altitude. Use a series of chambers supplied with varying amounts of air and oxygen. Test the effects of reduced oxygen pressure on experimental animals. Relate the reduced oxygen pressure in the chambers to reduced barometric pressures at altitude. What does this tell you about the effects of reduced oxygen pressure on the flier at high altitudes? What is hypoxia? How does it affect fliers? What is done to prevent hypoxia?

2. With the help of the physics teacher, set up an experiment demonstrating the operation of Boyle's law. the volume of a gas is inversely proportional to its pressure if the temperature remains constant. How does this law explain the presence of trapped gases in the body at altitude?

3. With the help of the physics and biology teachers, set up an experiment demonstrating the mechanical operation of the lungs. You might use a large jar and a small balloon and pump. Explain to the class why we had to learn about the mechanical process of breathing before we could make workable oxygen systems. What happens to the breathing cycle during pressure breathing?

4. Make a study of the circulatory system. Make a diagram or model to show how the heart pumps blood to the principal parts of the body.

Explain how oxygen is supplied to the cells. What happens to the circulatory system under reduced pressure at altitude?

5 Explain to the class the means that can be used to prevent an ear block. Demonstrate the valsalva procedure. This is done by closing the mouth, holding the nose, and blowing. This action forces air up the eustachian tube into the middle ear. Draw a diagram to explain to the class what happens during the valsalva procedure. How is pressure in the middle ear usually equalized with that of the ambient atmosphere during descent? Why does the airline hostess usually waken sleeping passengers before descent?

6 Explain to the members of the class the cause of decompression sickness. A simple way is to take the cap off a pop bottle and have them watch the bubbles escape A similar phenomenon occurs when nitrogen evolves, or goes out of solution in the body, at altitude. The nitrogen bubbles off from the blood and other body fluids and collects at the joints. (This process cannot, of course, be seen. You might draw a diagram to show bubbles forming inside the body at a joint.) The flier (or deep-sea diver) may bend over from pain. This is why this form of decompression sickness is called the bends. The bubbles are minute and very numerous. What are other forms of decompression sickness besides the bends? How is decompression sickness treated in a pressure chamber?

7 Why is good vision important to the flier? Demonstrate to the class how the pilot has few visual cues during flight. Explain what happens when the pilot mistakes a bank of clouds for the horizon. What are some other visual illusions that a pilot might have during flight?

8 A group of four to six students might form a team to make a study of balance and orientation during flight. Three of the group might submit themselves to being spun around on a rotating chair and describe their sensations. Demonstrate to the class that the students are disoriented. What three means does a pilot use to maintain balance and orientation during flight? One of the students in the group might use a diagram or model of the inner ear to explain what happens to cause disorientation during flight. Explain the purpose of the semicircular canals and the otolith organs.

SUGGESTIONS FOR FURTHER READING

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THIS CHAPTER explains how specialists in the field of aerospace medicine and human engineering have combined their knowledge and skills to enable man to progress in flight through the atmosphere to the fringe of space. The chapter relates how early balloonists and physiologists studied the lower atmosphere and how aerospace medicine and human engineering began. Next it explains the services performed by flight surgeons and human engineers. Finally, the chapter tells how test pilots and later balloonists helped to make flight safe in high performance aircraft and how they and animal astronauts prepared the way for spaceflight. After you have studied this chapter, you should be able to do the following: (1) explain how the early balloonists and physiologists prepared the way for aircraft flight, (2) tell three services that a flight surgeon performs for fliers, (3) explain how the human engineer matches man and machine, and (4) describe two flights made in the upper atmosphere and tell how they prepared the way for spaceflight.

WHEN MAN first climbed into an airplane to go aloft some seventy years ago, he had to adjust to the cramped quarters of the cockpit and to the noise and vibration of the engine. None of the early flights lasted long enough or went high enough, however, to cause serious flight stresses.

By the time of World War II, aircraft had undergone many changes, and flight stresses were becoming severe. The P–38 Lightning, which first saw action in 1941, was finally able to fly at speeds of more than 410 mph and at altitudes as high as 35,000 feet. The P-47, which came into use about the same time, reached speeds of more than 425 mph and flew as high as 42,000 feet. The P-80 Shooting Star, America's first operational jet fighter, first announced in 1944, was finally capable of speeds of more than 550 mph and of altitudes over 45,000 feet. To defeat the enemy, a pilot had to be able to take his aircraft to the limits of its speed and maneuverability and to its altitude ceiling. In flying in a hostile environment and in maneuvering, pilots were being subjected to all kinds of flight stresses.

To counter the stresses of flight in high-performance aircraft, man has had to learn more about the human body and the way it reacts to flight, and he has had to learn how to design and produce more efficient kinds of protective equipment and clothing. The present-day knowledge of flight physiology, outlined in Chapter 1, was developed through a branch of medicine now known as **aerospace medicine.** Medical knowledge formed the foundation, but this knowledge had to be combined with the knowledge and skill of engineers. The branch of engineering that specializes in meeting the human requirements of flight is called **human engineering.**

The challenge has been to bring together the knowledge and skills of specialists in both the field of aerospace medicine and human engineering in order to produce practical results. The results have taken the form of better designed aircraft, improved oxygen systems and pressure suits, and finally the pressurized cabin.

Aerospace medicine includes both aviation medicine and space medicine. Since there is no real boundary line between air and space, as pointed out in Chapter 1, there can be no real division between aviation medicine and space medicine, and the two are now considered as one branch of medicine. Aerospace medicine is concerned mainly with the injuries and problems brought about by stresses from flight through the atmosphere and space, and our survey focuses on these.

BEGINNINGS OF AEROSPACE MEDICINE

Aerospace medicine was established in the United States with the founding of the first Army aviation medical research laboratory at Hazelhurst Field on Long Island, New York, in 1918. Research conducted in this laboratory was to give support to our fliers during World War I. The real beginnings of aerospace medicine go back much earlier, however, to studies with balloons. The earliest studies with balloons provided for a gradual accumulation of knowledge about flight stresses long before aircraft were flying.

Balloonists and Early Studies of the Atmosphere

The study of flight physiology started with the balloon ascensions of the Montgolfier brothers, Joseph and Etienne. In 1783 they sent up a hot-air balloon in a demonstration for Louis XVI of France and his court at Versailles. This was a kind of preliminary unmanned flight made with a sheep, a cock, and a duck. The passengers rose to an altitude of 1,500 feet and returned to the earth unharmed, to the wonderment of those assembled.

In the same year the French physicist Jacques Charles made a flight with a hydrogen balloon that floated free. When he ascended to an altitude of 9,000 feet, he suffered a severe pain in his right ear, which he correctly attributed to gas trapped in the middle ear.

In 1785 the American doctor John Jeffries, with French balloonist Jean-Pierre Blanchard, crossed the English Channel with a hydrogen balloon (Fig. 20). This long-range balloon flight created about as much excitement as any later event in aviation. On this, their second balloon flight, the two men carried a thermometer, a barometer, and other instruments to study the upper air. As they took off from Dover, their balloon began to rise at an alarming rate. They hastily released gas and probably released too much.

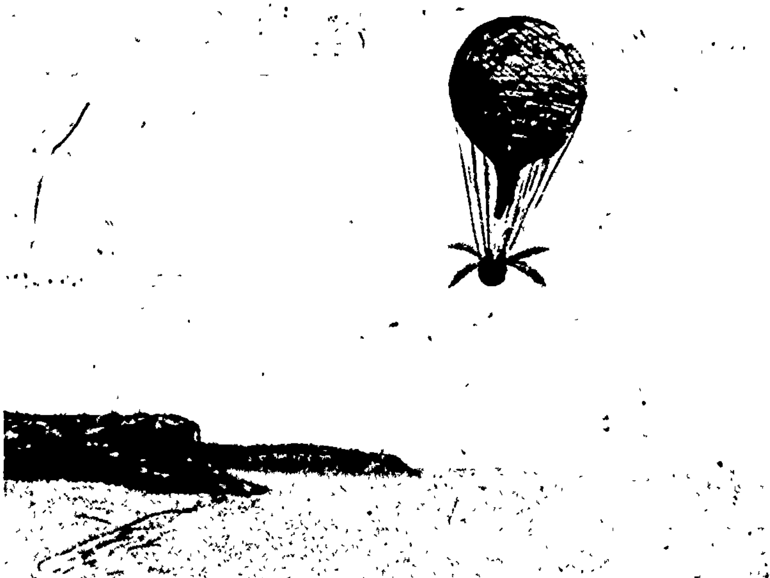

Figure 20. Balloon flight of Jeffries and Blanchard. The oars were intended to help steer the balloon. They did not work and were discarded, together with other equipment.

About halfway across the Channel the balloon began to drop. To avoid disaster, the two men began throwing objects overboard to lighten their load. After they sacrificed their scientific instruments, the balloon began to rise again. Everything again went well until they approached the coast of France. Then the balloon began to descend rapidly, and from this point on it was one constant struggle. To lighten the load, the two passengers began to disrobe and discard their clothing. Finally the balloon was over the treetops, and they maneuvered it to a safe landing, shivering and almost naked. Jeffries and Blanchard were given a hero's welcome in Calais and then Paris. Doctor Jeffries returned to the United States to write of his experiences. The John Jeffries Award is presented each year to the doctor who makes the greatest contribution to aviation medicine.

After the Channel crossing, an interest in balloon ascensions swept over Europe. Hundreds of flights were made, some simply for the thrill but many in the interest of science.

A flight of special scientific interest was that made by two Englishmen, Coxwell and Glaisher (Fig. 21). After 27 other flights, also sponsored by the British Association for the Advancement of Science, these two men made their historic flight in September 1862. When they reached an altitude of 18,000 feet, their troubles began. Because of lack of oxygen, they became so weak that they had difficulty in reading their instruments. Unfortunately, the balloon cord became tangled, and they could not release gas to allow the balloon to descend. Instead they continued to go higher. Before long Glaisher lost his vision, and in total darkness at 29,000 feet he lapsed into unconsciousness. Finally he recovered consciousness and continued to observe his symptoms. Coxwell's hand had become numb from the cold, but he was finally able to grasp the balloon cord with his teeth and release gas. The balloon descended, and both passengers survived. Glaisher later described his symptoms of oxygen starvation in graphic terms.

Soon after the flight of Glaisher and Coxwell, Paul Bert (1833-1886), a French physiologist, conducted the experiments with barometric pressure which he later described in his famous book. Bert rather than the balloonists became known as the Father of Aviation Medicine. As early as 1870 Bert put sparrows in sealed glass jars of various sizes which were filled with oxygen and air-oxygen mixtures. He was studying the effects of these different atmospheres on survival. During the next eight years Bert was to conduct some 700 experiments with varying atmospheric pressures. In his experiments he related the conditions of increased atmospheric pressure for men working underwater with those of

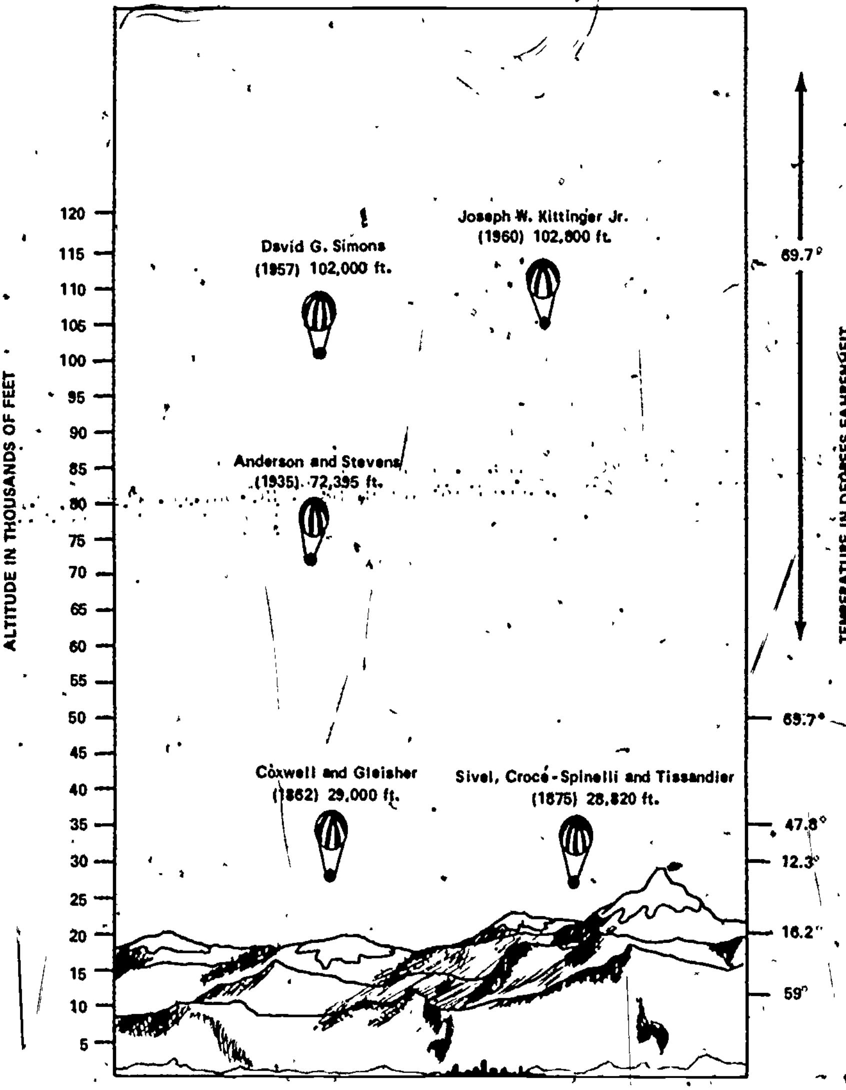

Figure 21 Some record balloon flights Balloons have now penetrated the atmosphere to their ceiling. A pressurized gondola is required for balloon flights above the 50,000-foot level unless the occupant wears a pressure suit.

decreased atmospheric pressure encountered in mountain travel and high-altitude flight. Bert was able to prove that the principal effects of altitude on the body are caused by the partial pressure of oxygen. Bert also made the first low-pressure chamber, or **altitude chamber.** This is an airtight tank (Fig. 22) in which the atmospheric pressure can be varied to simulate any altitude of flight.

After Paul Bert had conducted experiments in his altitude chamber in Paris, two balloonists visited him. The balloonists, Sivel and Crocé-Spinelli, subjected themselves to low pressures in the chamber and learned how to protect themselves through the use of oxygen. After making a successful high-altitude balloon flight, with the aid of bags containing a nitrogen-oxygen mixture, they decided to try a second experiment. On this trip, made in 1875, they were accompanied by a third balloonist named Tissandier. Unfortunately, the three balloonists did not provide themselves with enough oxygen, and they decided to refrain from using it as long as they could. Bert sent them a warning, but the letter did not arrive in time, and the balloonists went ahead with their

Figure 22. Altitude chamber used in the 1950s. These students are learning how to use oxygen breathing equipment during a simulated flight.

plans. By the time they were aloft and were aware they were suffering from oxygen starvation, they had already become paralyzed and could not make use of their meager supply of oxygen. They became unconscious as a result. Their balloon ascended to 28,820 feet and then descended on its own, carrying the unconscious occupants back to earth. When Tissandier revived, he found that his two companions were dead. The tragedy caused Bert to renew his efforts to protect man against oxygen starvation.

Schools of Aviation Medicine

Almost two decades after Bert's death, interest in flight physiology was revived when the Wright brothers successfully flew the first airplane. Further interest in aviation medicine was stimulated during World War I. During the war Gen. Theodore C. Lyster was appointed Surgeon General of the Aviation Section of the Signal Corps, US Army. General Lyster is known as the Father of Aviation Medicine in America. He was responsible for establishing the research laboratory at Hazelhurst Field, in New York, which eventually developed into the Air Force School of Aerospace Medicine, now located at Brooks Air Force Base, Texas.

The Navy, like the Army and Air Force, did early research in aviation medicine. The Navy established a School of Aviation Medicine at the Naval Air Station at Pensacola, Florida, in 1939.

Among the pioneers in research in aerospace medicine was Gen. Harry G. Armstrong, who served as commandant of the Air Force school in Texas and as Air Force Surgeon General. He compiled a standard textbook of aviation medicine, and under his direction a department of space medicine was founded at the Air Force school as early as 1949. This department was headed by Dr. Hubertus Strughold, who had served as a flight surgeon for the German Air Force during World War II. Doctor Strughold became a pioneer in space medicine in the United States just as Wernher von Braun pioneered in the development of US space boosters.

Other Organizations Supporting Aerospace Medicine

Another important development in aviation medicine was the founding of medical and biological departments in aircraft manufacturing companies. The very fact that such departments were set up showed that aircraft companies were becoming aware of the importance of human requirements in designing aircraft.

In 1929 Dr. Louis H. Bauer founded an organization for professional workers interested in the human aspects of flight. The organization is at present known as the Aerospace Medical Association, and it is an international organization. It comprises not only doctors but also other medical specialists, life scientists, and engineers who are concerned with the medical aspects of flying and the adaptation of man to the environment in which he flies. The organization focuses its interest on the care of fliers.

CARE OF FLIERS

The Armed Forces have doctors who receive special training in the care of fliers at the service schools of aerospace medicine. These doctors are called **flight surgeons.** A flight surgeon is not required to be a pilot, but he does fly as a crew member. The more he knows about flying, the better able he is to administer to the needs of fliers. Ordinarily doctors do not accompany patients who are being evacuated by air. Patients en route to hospitals are placed under the care of flight nurses and medical technicians. Flight surgeons remain on the ground to be in readiness to care for fliers at a base or medical center.

The high-performance jet aircraft of today make demands on military pilots of an order scarcely imagined before World War II. The military services realize that it may well be man's adaptation to flight rather than the performance of his aircraft that determines the victor in any future conflict. The jet pilot's proficiency depends upon his ability to react instantly and make decisions under stress. To maintain his proficiency, the pilot must keep his mind and body fit at all times. It is the flight surgeon who helps him do this.

The flier knows that it is the flight surgeon who must also pass on his physical and mental fitness for flying (Fig. 23). It is the flight surgeon who gives him the periodic examinations that determine whether he can continue on flight status. Even though the pilot knows that the flight surgeon can ground him he must not keep from him any knowledge that might have a bearing upon his fitness to fly.

For the military flier the flight surgeon is not only a personal physician but a counselor and friend as well. The flight surgeon lives and works with the fliers during combat. He is interested in the flier's personal problems, as well as his physical condition, because he knows that a man's mental and physical condition are closely related. If, for example, a flier is worrying about his family, he may develop a severe headache. This, in turn, can trigger

Figure 23 Flight surgeon examining pilot. The flight surgeon keeps a constant watch over the flier's health.

digestive disturbances. These additional stresses may dull the pilot's senses and cause him to use poor judgment, which may cause an accident.

Besides having concern for the pilot himself, the flight surgeon is interested in the conditions the pilot finds in the cockpit. He wants to know if the pilot's oxygen equipment and clothing are adequate He makes sure that there is enough oxygen in case of rapid decompression and that there are no flaws in the ejection equipment Since the flight surgeon takes part in the investigation of aircraft accidents and treats the injured, he is aware of what is needed to make flying safe. He urges the flier to observe safety precautions and to make full use of seat belts, shoulder harnesses, and other protective equipment. Because flight surgeons, as well as the doctors who care for civil pilots, have an all-round understanding of the flier's problems, they are in a position to advise engineers about how to bring together man and machine.

MAN AND MACHINE

One course that man can follow in adjusting to flight is to design the flight machine in such a way as to eliminate or reduce stress on the human body. This course is pursued through human engineering. This is an art and science that relates man to the aircraft and the systems in it (Fig. 24). The human engineer uses knowledge about the life sciences to promote efficiency and safety in those areas where man and machine come into contact with each other. For example, if the pilot has difficulty in using a hand control for a particular task, the engineer might design a control operated by a foot pedal, leaving the pilot's hands free for other tasks.

The matching of man and machine is constantly under study by the departments of human engineering in companies manufacturing aircraft. Experts in these departments make use of the services of a host of specialists, such as biologists, blood specialists, heart specialists, psychologists, and electronics engineers.

About the time that high-performance jets were coming into production, the Air Force adopted systems management for aircraft. Under this plan each aircraft is developed as a unit, or system. Instruments and controls, training, and protective equipment—the human requirements—are considered an important part

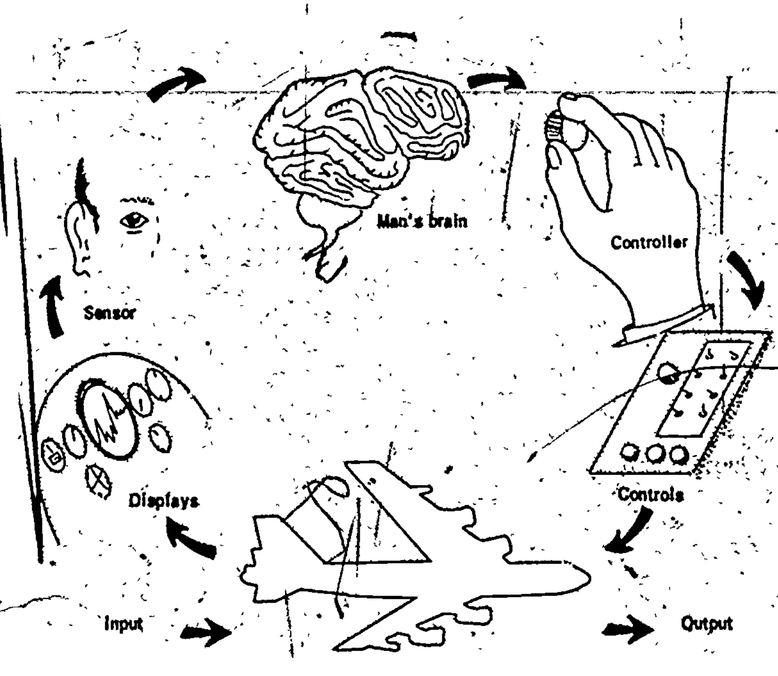

Figure 24. Man machine system. To fly a high performance aircraft man must become part of the system. He uses his eyes as sensors to read the displays on the instrument panel. His brain interprets what he sees. Then his brain sends messages to his hands and feet to tell them how to operate the controls.

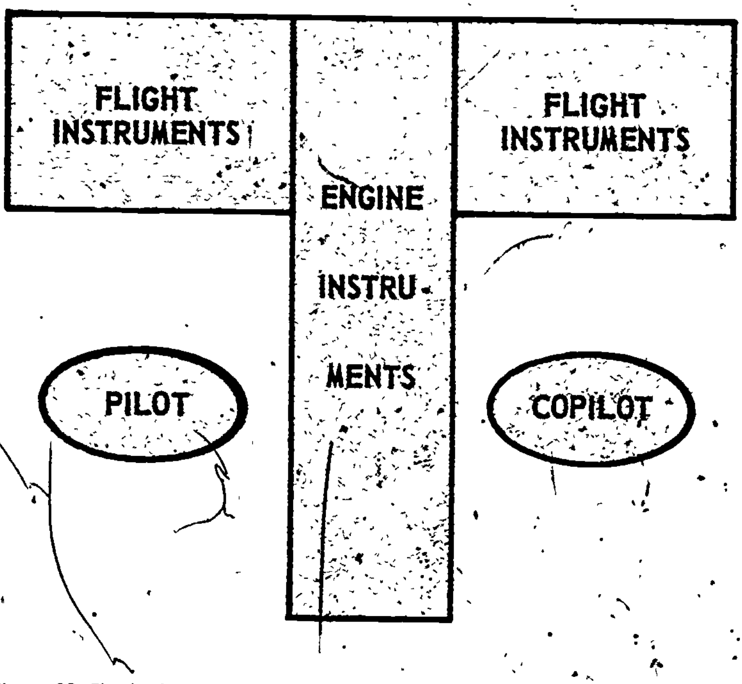

Figure 25. The basic T arrangement. The flight instruments in an aircraft are placed directly in front of the pilot or copilot. The engine instruments are in a bar perpendicular to the flight instruments.

of each aircraft system. No longer can pilots say that engineers design aircraft without regard to their needs.

Every control and instrument in the aircraft must be developed and positioned with the pilot in mind. Every time an instrument or a control is put into a new place, the pilot must relearn skills, much as the driver of a new model car must learn a new dashboard But because an aircraft instrument panel is far more complex than the dashboard of an automobile, the task is far more difficult In military aircraft there has been some standardization of the instrument panel ever since high-performance aircraft came into use. It is only in recent years, however, that agreement has been reached permitting a standardized arrangement of the instrument panel for both civil and military aircraft. The arrangement now agreed upon is called "the basic T" (Fig. 25). Under this plan the flight instruments are grouped across the top bar of the T, and these are conveniently placed in front of the pilot and copilot The engine instruments are placed in the other bar of the T, the vertical bar, and these are positioned to the right of the pilot and to the left of the copilot.

Another area in which human engineering is important is in that of **servomechanisms** used in aircraft. These are the automatic mechanisms which multiply the force exerted by a pilot to increase his control, much as power steering and power brakes increase the driver's control in an automobile. To give the pilot the power that he needs, power-operated controls are a necessity in high-performance aircraft. They do have certain disadvantages, however. They are complex and heavy, adding to the weight of the aircraft. To the pilot they present a real problem. They take away from him much of the feel of control that he formerly had over his aircraft—what he calls the "feel of flying." The pilot must now truly become a part of the machine, learning to fly within the circuit of power controls as well as communications equipment.

Another area in which human engineering has played an important part is in designing protective equipment for flight. In this field doctors have worked closely with engineers. They have also teamed with engineers in planning programs for pilot training and in designing flight simulators for these programs. The practical results of their work—protective equipment and pilot training—are described in Chapter 3. In this chapter we are concerned mainly with research for advancing flight through the atmosphere to the lower reaches of space.

RESEARCH ON THE FRINGE OF SPACE

Just as scientists and balloonists collected information on the lower atmosphere long before aircraft flew, scientists, pilots, and balloonists investigated the lower reaches of space before man rocketed into space. For these investigations on the fringe of space they used special research aircraft, balloons, sounding rockets, and spacecraft with animals on board.

Research Aircraft

The US series of research jet and rocket aircraft, or the X series, concluded with the X-15, a black needle-nosed rocket aircraft with stubby wings. This aircraft collected data directly related to spaceflight. Two earlier research aircraft, the X-1 and the X-2, were useful in advancing from aviation to spaceflight. These and other research aircraft were flown by highly skilled test pilots. Test pilots have played an important role in adapting man to flight and in pushing forward the frontiers of flight.

In the X-1 (Fig. 26), the first US rocket aircraft, Air Force Capt. Charles E. Yeager became the first man to fly faster than

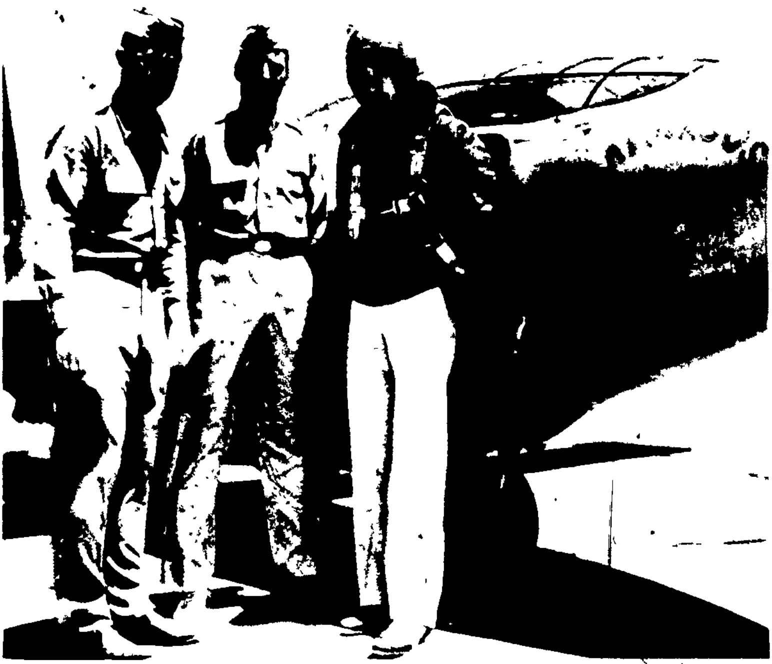

Figure 26. X-1 and test pilots. Capt. Charles E. Yeager is in uniform and is standing at the extreme left.

the speed of sound. This was in October 1947. When pilots before him had attempted to reach the speed of sound, they were subjected to severe buffeting as the shock waves formed in front of their aircraft, and they could not fly faster. As Yeager's aircraft approached the so-called **sonic barrier,** the buffeting became so severe that for a time it seemed that the aircraft would break apart. Then the X-1 exceeded the speed of sound, and the shock waves were behind it. On his historic flight Yeager was protected by a partial-pressure suit that Doctor Henry had made especially for him. Yeager's mask was not a true helmet but a kind of nylon sack laced in place, yet it was successful in providing necessary pressurized oxygen.

The next obstacle to overcome was the so-called **heat barrier.** The supersonic X-2 was subjected to intense frictional heating even in the cold, thin atmosphere at its altitude ceiling. The pilot was protected with cooling equipment for his pressure suit, but the outside of the aircraft was scorched from aerodynamic heating. When Capt. Melvin Apt attempted to take the X-2 to record altitudes at increased speed, the aircraft overheated. Both pilot and aircraft were lost. Then engineers developed new strong lightweight metal alloys, such as titanium, which could withstand greater heat stress, and the flights of research aircraft continued.

The X-15, the last aircraft of the research series, was used to collect a whole range of physiological data on flight at record altitudes and speeds. This aircraft reached a speed of 4,534 mph and an altitude of 354,200 feet (about 67 miles). Several pilots flying the X-15 were able to earn an astronaut rating by taking this aircraft above 50 miles. The first of these pilots was Air Force Maj. Robert M. White (Fig. 27), now General White, Commandant of Air Force ROTC.

There were three models of the X-15 aircraft. Although some two hundred hazardous flights were made with these three aircraft, only one pilot and aircraft were lost. The X-15 was one of the most important links in the transition from aviation to spaceflight. Its later flights were actually made to collect data for future flights of the Mercury and Gemini spacecraft. The last flight of the X-15 (the 199th flight) was made in October 1968. For fuller protection during flight the pilot of the X-15 wore a full-pressure suit.

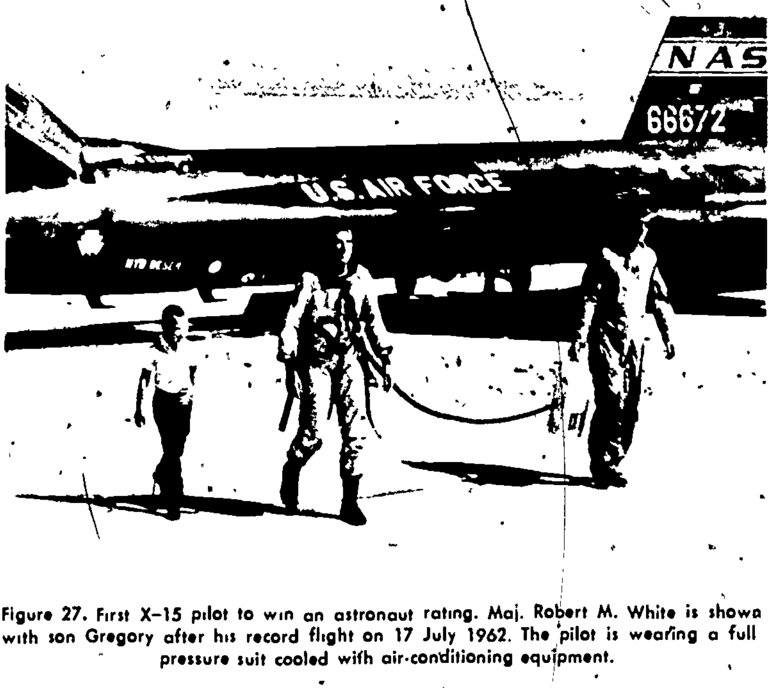

Figure 27. First X-15 pilot to win an astronaut rating. Maj. Robert M. White is shown with son Gregory after his record flight on 17 July 1962. The pilot is wearing a full pressure suit cooled with air-conditioning equipment.

Balloons

Even before the flight of the US research aircraft began, scientists resumed balloon flights to learn more about conditions in the upper reaches of the atmosphere. Balloons are especially valuable for collecting physiological data because they can descend quickly in an emergency. Then, too, the balloonist is not distracted by problems of piloting and control, and he is not subjected to high G-forces.

In 1931, Auguste Piccard, a Swiss physicist and aeronaut, perfected the oxygen-pressure gondola for balloons to be used for scientific exploration. Making use of the principle developed by Piccard, Captains Orvil A. Anderson and Albert W. Stevens, of the US Army Air Corps, ascended to what was then the remarkable altitude of 72,395 feet (Fig. 21). This was in 1935, two years before the first pressurized cockpit was used in an American aircraft For the **pressurized gondola** of their balloon Anderson and Stevens used a mixture of oxygen and nitrogen (about 50-50). After 1935 many balloon flights were made to investigate the conditions of the upper atmosphere.

One of the Air Force balloon projects was called Man High. For the principal Man High flight, the Air Force chose Maj. David G. Simons (Fig. 28). In August 1957, Simons ascended to a height of 102,000 feet. The flight lasted 32 hours 10 minutes. At his highest altitude, Simons observed a black sky above him, and he could see the curve of the horizon. To record any cosmic radiation at this altitude, Simons wore special photographic plates mounted on his arms and chest. He also had with him some black mice for testing the physiological effects of cosmic radiation. No immediate effects were noted from the exposure, but the black mice later became speckled with gray, indicating premature aging from cosmic radiation.

During his flight Simons was protected by a sealed pressurized gondola containing a mixture of oxygen, nitrogen, and helium. Although provisions were made for purifying the atmosphere, the carbon dioxide content of the sealed gondola became dangerously high. Simons evaluated the risks and remained aloft.

The Man High flights were followed by the Excelsior balloon flights made by Air Force Capt. Joseph W. Kittinger, Jr. The Excelsior flights, begun in November 1959, were made for the purpose of testing aircraft ejection equipment. Kittinger had prepared for his balloon flights by assisting Major Simons with the Man High project. On his flights Kittinger rode in an open gondola protected only by his oxygen supply and pressure suit (Fig. 29).

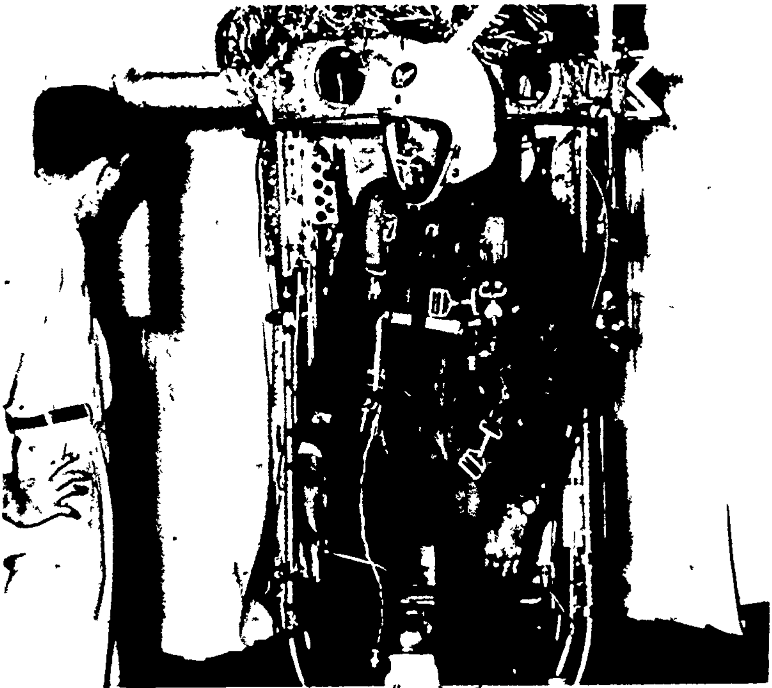

Figure 28. Maj. David G. Simons standing beside his balloon capsule. Simons reached an altitude of 102,000 feet on 20 August 1957.

On the first flight, as Kittinger prepared to jump from the gondola at an altitude of 76,400 feet, his altimeter caught on the door. The delay caused in freeing himself upset the automatic timing device on his parachute. As a result, Kittinger's parachute opened too soon, the cord tangled in his clothing, and he was spun violently during his descent. Fortunately, he was able to right himself and make a safe landing.

The second and third Excelsior balloon flights were completely successful. On the third Excelsior flight, Kittinger ascended to the height of 102.800 feet, slightly higher than Simons' maximum altitude. After Kittinger jumped from the balloon gondola, he kicked and moved his arms about to maintain stability during **free fall** (Fig. 30). During the descent Kittinger reported on his sensations by talking into a tape recorder fastened to his body.

Kittinger's parachute jumps showed that pilots could eject safely at very high altitudes, on the very fringe of space. Years later, during combat in Vietnam, Kittinger made another parachute jump that took him through danger to safety. Upon landing, he was

Figure 29. Capt. Joseph W. Kittinger, Jr., beside open gondola used on Excelsior flights. Kittinger was protected by his pressure suit and oxygen equipment.

captured by the North Vietnamese and held prisoner but was released early in 1973.

The balloon flights ended at the ceiling for winged aircraft and air-breathing vehicles. Through the use of rocket power, animal astronauts could be launched into space to prepare the way for man.

Animal Astronauts

After scientists and engineers began experimenting with rockets following World War II, medical researchers sent animals into the upper atmosphere to test conditions there and to find out how living matter reacted to spaceflight. Dr. James Henry performed some of the early experiments with animals at Holloman Air Force Base, New Mexico Since the first rockets could carry only small payloads, mice and other small animals were used for the early

Figure 30. Captain Kittinger during free fall. He moved his arms and legs to maintain stability

experiments. When these small animals were rocketed into space, they had to be protected with a pressurized environment and had to be provided with food and water. Scientists made the first crude **space capsules** to protect the subjects of their experiments.

As rockets became more powerful and larger payloads could be sent into space, American researchers used larger animals for their experiments, and they constructed better space capsules. While Soviet scientists prefer dogs for their space experiments, American scientists have used monkeys and chimpanzees. Since these animals are higher in the animal scale, they have a physiology that more nearly resembles man's, and they can be more highly trained. Soviet scientists, on the other hand, have collected a large body of physiological data about dogs, which enables them to make comparisons. The Soviet dog Laika, a female of the

Husky breed, was the first animal to be rocketed into orbit. Laika survived in orbit for about seven days and then died there.

About a decade before the Mercury astronauts made their first flight, US researchers sent chimpanzees and monkeys into space on sounding rockets.

Two of the first chimpanzees to go into space were Pat and Mike. They made the trip on an Aerobee rocket in May 1952 in order to test G-forces during spaceflight. One animal was seated, and the other was lying. Although the seated animal took the more severe punishment from G-forces, telemetered data showed that neither animal suffered ill effects from the flight.

In May 1959 two monkeys, Able and Baker, were sent aloft on a Little Joe rocket to test protective equipment. Each monkey traveled in a separate sealed capsule. Each wore a specially designed space suit and helmet and reclined on a contoured couch, with legs drawn up (a position intended to give the best protection against G-forces). After the space travelers were recovered and given a thorough examination, the flight was pronounced a success.

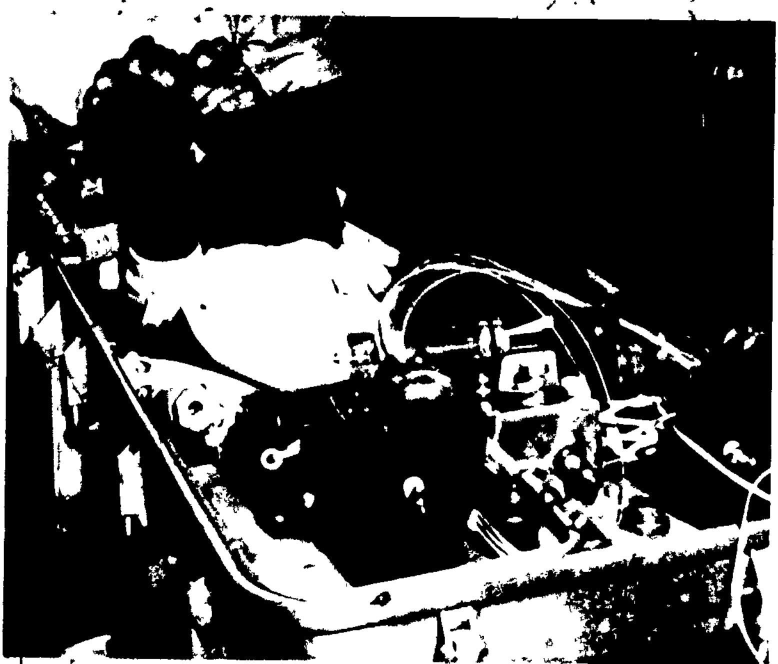

Figure 31. Enos fitted into pressure couch. This chimpanzee was used to test the Mercury spacecraft in orbital flight.

Before American astronauts were rocketed into space, two chimpanzees were used to test the Mercury spacecraft and the flight plan for it. Ham prepared the way for the first suborbital flight by Astronaut Alan Shepard, and Enos (Fig. 31) orbited in space before Astronaut John Glenn made the first US orbital flight.

Enos, like all animal astronauts, was carefully selected and trained. Results were gratifying. Enos did all the tasks assigned to him. He worked to get at his water and food, and then showed scientists that it was possible to eat and drink while in orbit. When the capsule was recovered, Enos's space suit was drenched with perspiration, but he was alert and excited. He popped out of the capsule, wobbled a bit, and finally began to jump for joy. Then he went the rounds to shake the hands of his rescuers. A few hours later space official announced that the United States was ready to send the first astronaut into orbit.

The way for man into space had been prepared by some fifty years of research in aerospace medicine and by more than a century of study of flight physiology. Many questions about spaceflight still remained unanswered, however, as the first astronauts prepared to go into space. To understand how the astronauts have coped with the stresses of spaceflight, it is first necessary to know how we developed protective equipment for aircraft flight and how pilots are trained to fly aircraft.

TERMS TO REMEMBER

aerospace medicine
human engineering
altitude chamber
flight surgeons
servomechanisms
sonic barrier
heat barrier
pressurized gondola
free fall
space capsule

PRONUNCIATION

Montgolfier (mohn gol fee YAY)
Versailles (ver SIGH)
Jacques (jock) Charles (SHARL)
Calais (kahl LAY)
Crocé-Spinelli (KROH chay Spin NEL LEE)
Tissandier (tee sahn de AY)
Auguste Piccard (pee KAHR)

QUESTIONS

1. What contributions did the early balloonists make to flight physiology? What kind of experiments did Paul Bert perform?
2. What is aerospace medicine? What professional services do flight surgeons perform for fliers?
3. How are man and the flight machine made to work together?
4. What were the X series of aircraft? Who flew the X-1, and what did it accomplish? How was the X-15 used?
5. What contributions did advanced balloon flights make to the study of flight physiology?
6. How did the animal astronauts prepare the way for manned spaceflight?

THINGS TO DO

1. Make a study of one of the early balloon flights, such as that of Jeffries and Blanchard or of Sivel, Croce Spinelli, and Tissandier, and tell what the flight contributed to our knowledge of flight physiology. Why were the flights of the early balloonists important in the study of flight physiology?
2. If you are interested in medicine, make a study of one of the physiologists or doctors who made a significant contribution to aerospace medicine. You may wish to select one of the early contributors mentioned in this chapter, such as Paul Bert, Dr. John Jeffries, or Gen. Harry G. Armstrong, or you may wish to study about the research done for the Air Force by Dr. James Henry or Col. Paul Stapp, which is described in Chapter 3.
3. The X-15 was the last of the X series of research aircraft. Many exciting flights were made with the X-15. Select one of the test pilots who flew the X-15 and tell about his most important flight. Concentrate on the biomedical aspects of the flight. What kind of protective clothing did the pilot wear? How was the aircraft pressurized?
4. Make a study of one of the more recent balloon flights, such as that of Major Simons or Captain Kittinger. What biomedical findings were made? What did the flight contribute to our knowledge of flight physiology?
5. Make a study of the flight of one or more of the most important animal astronauts. What biomedical findings were made on the flight? How was the animal(s) protected and life support given? How did animal astronauts prepare the way for manned spaceflight?

SUGGESTIONS FOR FURTHER READING

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Protective Equipment and Pilot Training

THIS CHAPTER describes the protective equipment and the pilot training that make flight possible in modern high-performance aircraft. It explains how oxygen masks, pressure suits, and G suits are used to protect pilots and aircrews, how the pressurized cabin operates and how aircrews and passengers are protected against rapid decompression, and how military pilots and aircrews bail out and use ejection seat systems to escape from aircraft. Next the chapter surveys military and civil pilot training programs and describes the different kinds of flight simulators used in training. After you have studied this chapter, you should be able to do the following: (1) explain how pilots and aircrews are protected by oxygen masks, pressure suits, and G suits; (2) identify the two kinds of pressurized cabins and explain why the pressurized cabin was important in advancing commercial flight; (3) describe the operation of a parachute and of an ejection-seat system; and (4) explain how the low-altitude chamber and sophisticated simulators giving the feel of flight are used in training pilots.

THE TWO PRINCIPAL means for meeting the human requirements of flight are the use of protective equipment and the training of pilots. Without a whole range of protective equipment and without realistic training programs, man could never have [illegible] faced [illegible] the physiologically deficient zones of the atmosphere, [illegible] he would never have been able to cope with space conditions.

In the progress of aviation, the breakthroughs made in meeting the human requirements of flight have been as significant as the breakthroughs in engineering that produced jet engines, sweptback wings, and lighter and stronger aircraft structures. The decade of the 1950s, which produced the high-performance aircraft, also brought about the greatest progress in developing protective equipment for flight.

PROTECTIVE EQUIPMENT

At present there are three kinds of protective equipment used in aircraft. (1) protective clothing and accessories, which include oxygen masks and pressure suits, (2) pressurized cabins, and (3) equipment for escape in an emergency. Oxygen masks, pressure suits, and pressurized cabins are used to supply an artificial atmosphere during flight. This atmosphere is needed both for breathing and for counterpressure against the body. Man cannot fly at high altitudes without taking with him an atmosphere containing adequate oxygen.

Protective Clothing and Accessories

Oxygen was first supplied by an oxygen mask and then by a pressure suit. In time engineers learned how to pressurize the entire environment of the cockpit or cabin. Now most high-flying aircraft have a pressurized cabin. But because there is always the possibility that this cabin might become depressurized during flight, oxygen masks or pressure suits are taken along for use in an emergency.

About 98 percent of all flights are made below 50,000 feet. Aircraft flying at the higher altitudes within this level make use of a two-way plan for protecting aircrews and passengers. (1) a pressurized cabin and (2) oxygen masks for backup.

The 2 percent of all flights made above 50,000 feet are made by combat or test pilots. Aircraft flying above 50,000 feet have a three-way plan for protecting pilots. (1) a space cabin, (2) a pressure suit for backup, and (3) a G-suit.

The pressure suit and the G-suit, which were developed to protect military pilots in high-performance aircraft, formed the basis for the space suits for astronauts and for protective equipment used in civil aircraft. In developing protective equipment for flight, doctors and engineers started with the oxygen mask.

OXYGEN MASKS.—There are three types of **oxygen breathing systems,** or **oxygen** masks with their tanks and other accessories. These are (1) the continuous-flow type for use up to 25,000 feet, (2) the demand type for use up to 35,000 feet, and (3) the pressure-demand type for use up to 45,000 feet (Fig. 32).

Almost all aircraft that fly at higher altitudes today are being equipped with the pressure-demand oxygen system. Even some of the older aircraft are being refitted with the equipment. Usually the **continuous-flow oxygen system** is used for passengers on commercial aircraft or military troop transports. The masks for the continuous-flow system (Fig. 33) are easier to put on, and the

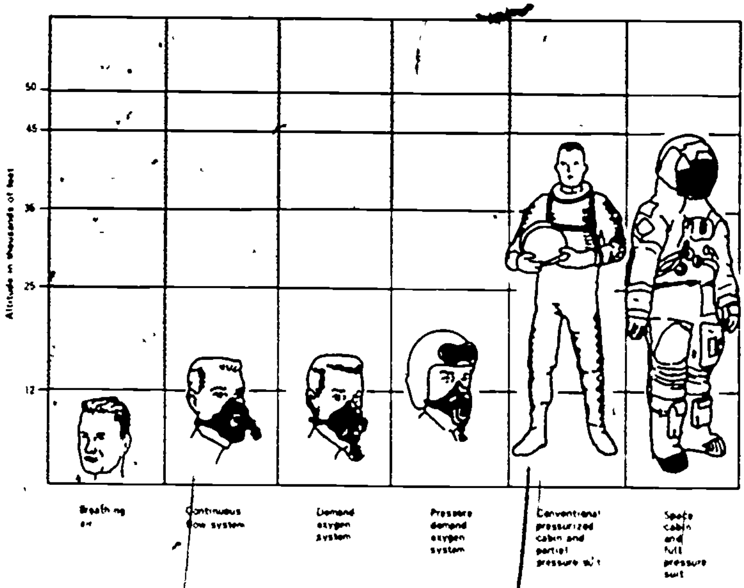

Figure 32. Flier's ceiling as raised by different kinds of protective equipment. The demand oxygen system is used routinely up to 35,000 feet, and the pressure-demand system up to 45,000 feet. Above 45,000 feet pressure suits are needed to back up a pressurized cabin.

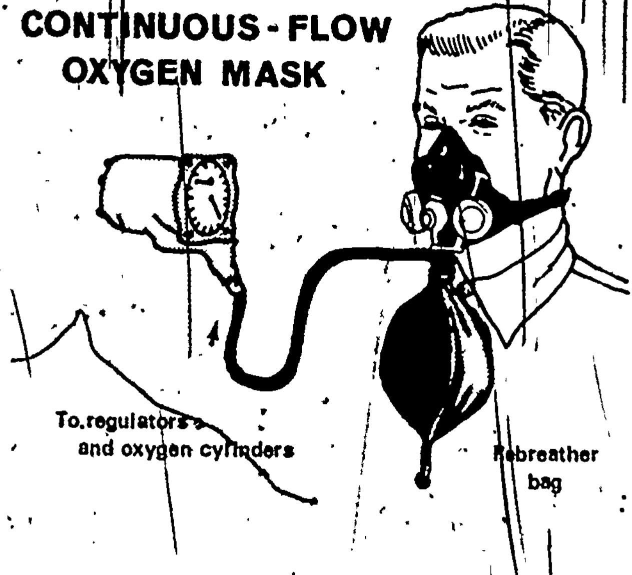

Figure 33. Continuous flow oxygen mask. With the continuous-flow oxygen system, a rebreather bag is usually attached to the mask. Oxygen is constantly dispensed from the storage cylinders through the regulating system to the bag and mask

passengers usually do not require as much oxygen as the pilot and other crew members do when making an emergency descent. The passengers are inactive and therefore do not have to have as much oxygen as the crew members flying the aircraft.

The pressure-demand oxygen system is a piece of equipment representing several stages of development. Tracing these stages enables one to understand how the modern complex system operates.

The first oxygen equipment, which the pilots called "dribble tubes," operated from a pipe stem. When the pilot needed oxygen he would pull on the stem, much as a man pulls on his pipe, and the pilot received a supply of cold, wet oxygen. Before and after pulls, the oxygen leaked.

As aircraft climbed higher, larger supplies of oxygen were needed, and a leakproof system was required. The answer was the oxygen mask, which fitted tight about the nose and mouth. At first a continuous flow of oxygen was supplied to the mask, and the oxygen could be taken from the ambient air.

When aircraft flew still higher, the amount of oxygen needed by the pilot increased greatly. At very high altitudes the pilot requires a higher proportion of pure oxygen. Very little of the required oxygen can be taken from the surrounding air. The solution was to shut off the flow of oxygen during the exhalation phase of breathing. Oxygen was supplied to the mask only when the pilot inhaled (Fig. 34). This system of supplying unpressurized oxygen upon demand, or the **demand oxygen system,** worked well until an altitude of 35,000 feet was reached.

From 35,000 to 45,000 feet, the pressure of the alveolar air (oxygen in the lungs plus water vapor and carbon dioxide) approaches the pressure of the ambient air. Under these conditions there is not enough oxygen entering the lungs to send an adequate supply to the bloodstream, and hypoxia results. To prevent hypoxia at altitudes up to 45,000 feet, the **pressure-demand oxygen system** is used (Fig. 35). This system supplies unpressurized oxygen in the right amounts at the lower levels. When the 30,000-foot level is reached, the system delivers 100 percent oxygen with the pressure adjusted to the altitude. In the more modern system the pressure is adjusted automatically. In the older type system the pilot has to adjust the settings manually.

Whenever a pilot breathes under pressure, his breathing cycle is reversed. In normal breathing his body uses muscle power to expand the chest cavity. This action creates lowered pressure in the lungs, and the air rushes into the lungs during inhalation, as explained in Chapter 1. During exhalation the chest cavity relaxes. In pressure breathing the process is reversed. The muscles of the

Figure 34. De[illegible]d oxygen mask. With the demand oxygen system, there is no rebreather ba[illegible]xygen is supplied to the user only when he inhales. The amount of [illegible]ygen supplied is adjusted automatically to the flight altitude.

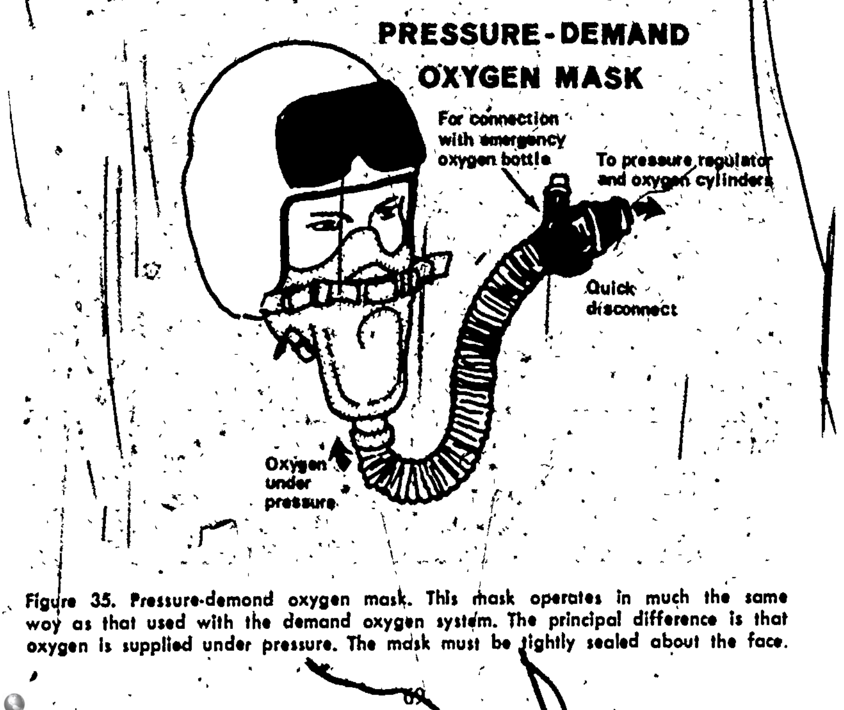

Figure 35. Pressure-demand oxygen mask. This mask operates in much the same way as that used with the demand oxygen system. The principal difference is that oxygen is supplied under pressure. The mask must be tightly sealed about the face.

chest cage are relaxed as oxygen is forced into the lungs during inhalation, but muscle power must be used to force exhalation. In other words, the pilot breathes *out* rather than *in* during pressure breathing. This breathing in reverse is tiring, and it can lead to hyperventilation if not carefully controlled.

Oxygen masks are used at high altitudes only in an emergency or for short periods of time to insure the safety of the crew. Whenever Air Force aircraft fly unpressurized above 13,000 feet, one member of the crew is usually kept on oxygen continuously. If possible, the pilot and copilot take turns wearing their oxygen masks. At altitudes from 40,000 to 45,000 feet all crew members wear pressure-demand oxygen masks continuously. Above the 45,000-foot level a pressure suit is usually used to back up the pressurized cabin. A mask is used above 45,000 feet only in an emergency. At the 50,000-foot level no oxygen will enter the lungs even if 100 percent oxygen is supplied under pressure.

PRESSURE SUITS.—Long before the 45,000-foot level was reached, pilots felt the need for having counterpressure against the body. The first **pressure** suit to provide this counterpressure resembled a deep-sea diver's outfit. It was designed by Wiley Post in the 1930s. In 1934 he wore the suit in his attempts to break the transcontinental speed record. The flights were made in the lower reaches of the stratosphere, where pressure breathing was not required. The suit that Post used successfully was actually the third suit that he designed. The first suit, which consisted of one layer of fabric, leaked badly. The second suit fitted too tight and had to be cut to free the flier. The third suit consisted of two layers. The inner layer was a rubber container for holding gas under pressure. To keep this container from ballooning out, there was a second layer of rubberized fabric that kept its shape and allowed the flier some mobility by using a pressure of about 7 psi. Wiley's third suit incorporated the **principle of layering,** or using layers of different materials to serve different purposes. Later pressure suits were developed upon this principle. Unfortunately, with Post's death in 1935, no further work was done on the pressure suit in the United States for more than a decade, but other nations took up its development.

During World War II both the US Navy and the Army Air Corps began research to develop a practical pressure suit for combat fliers. One of the pioneers in research on protective equipment for the Air Corps was Dr. James P. Henry. After completing work on a wartime research project on the circulatory system, Doctor Henry went to work at Wright Field to develop a pressure suit. At this time there was no such thing as a pressurized cockpit—only oxygen masks and a kind of pressure vest developed by the Royal Canadian Air Force. Doctors believed that if pilots were to be successfully provided with oxygen under pressure at extremely high altitudes, their bodies must be protected by being inclosed in a suit that would exert counterpressure against the entire body, not simply the chest and lungs. The theory seemed sound, but it had to be proved by developing a practical pressure suit.

Doctor Henry, clothed in a makeshift pressure suit that covered most of his body, gradually subjected himself to higher altitudes in the pressure chamber. Finally he reached a simulated altitude of 50,000 feet. When, in November 1944, the Air Force was ready to purchase a turbojet aircraft that would fly at 55,000 feet, Doctor Henry decided to develop enough counterpressure in his suit to go to an altitude of 58,000 feet and remain at that altitude for some time. This was a feat unheard of at the time.

Since Doctor Henry's pressure suit was crude, he made the simulated ascent to altitude gradually, pausing at various levels to breathe pure oxygen. Even so, he began to feel dizzy by the time he reached the 58,000-foot level. Although suffering from hypoxia, he kept up routine tasks to test the flexibility of the suit. He was so absorbed in his work that he did not notice the observers at the control window signaling to him. They wanted him to look at his right hand. When Doctor Henry glanced at it, he saw that it was blown up like a balloon. Suddenly the other hand reacted in the same way. General Armstrong, in early experiments, had observed similar ballooning of the bodies of rabbits in the pressure chamber at the same altitude. The controllers at the window decided that it was not safe to watch the phenomenon any longer. Without waiting for a signal from Doctor Henry, they brought him down from altitude.

The experiment showed that a pressure suit would protect man in the rarefied atmosphere at an altitude of 58,000 feet, but to do so the suit must completely inclose the body—hands, as well as trunk, head, and legs. Although the pressure suit that was developed covered the entire body, only part of the suit was pressurized. This is what is known as a **partial-pressure suit.**

At the same time that the Air Force began work on the partial pressure suit, the Navy was assigned the task of developing a full-pressure suit. After the Air Force produced a partial-pressure suit, its researchers also worked on the full-pressure suit. From the full-pressure suit developed for combat fliers came the first space suits for astronauts. The services plan to gradually replace the partial-pressure suit with a full-pressure suit.

A **full-pressure suit** (Fig. 36), which creates a completely pressurized environment, is the ideal backup for a pressurized cabin. It surrounds the wearer with a complete envelope of pressurized gas. This does away with the uncomfortable squeeze of the partial-pressure suit and allows more mobility and fuller protection. Most full-pressure suits are unpressurized as long as the aircraft is flying below 35,000 feet. As soon as the aircraft reaches this level or there is a loss of pressure from the aircraft cabin, the automatic controller on the suit causes it to inflate. The suit inflates to a pressure which, when added to that of the ambient atmosphere, equals about 3.5 psi. This is just about the same pressure as that of the earth's atmosphere at 35,000 feet. Therefore, a pilot wearing a full-pressure suit is never exposed to a pressure altitude greater than 35,000 feet regardless of the actual flight altitude.

At the present time the Air Force still uses many partial-pressure suits. The modern partial-pressure suit represents a whole series of improvements. It has been thoroughly tested under space-equivalent conditions and gives adequate protection. It is used only as backup to a pressurized cabin.

There are several models of Air Force partial-pressure suits but all have basically the same features. The suit consists of the pressure suit itself, helmet, and gloves (Fig. 37). The suit is constructed in layers. An inner layer consists of one large inflatable **bladder** that covers the wearer except for his head, arms, and lower legs. This provides counterpressure for the main part of the body, preventing expansion of gases and water vapor in the blood and tissues. Smaller bladders extend along the arms and legs to prevent pinching when the capstans are inflated. The **capstans** are inflatable tubes that extend along the arms, chest, thighs, and legs. When the capstans are inflated, they pull the suit tightly against the wearer's body to apply additional counterpressure against the expansion of gases and water vapor inside the body. The outer layer of the suit is made of nylon-cotton fabric with elasticized link net, or "fish net," in the areas where stretch is needed. The suit is closed with zippers, and laces provide some adjustment for size. The sealed **helmet** has a plastic facepiece, and it contains earphones, wires for communication, and wires for heating to prevent fogging of the helmet. The gloves for the suit contain small inflatable bladders.

Actually the modern pressure suit is not one but three pieces of protective equipment: (1) an oxygen mask, (2) a pressurized environment, and (3) a G-suit. Although the G-suit is usually sewn into the pressure suit and forms a part of it, the G-suit was developed separately and serves a separate purpose.

Figure 36. Full-pressure suit. This kind of suit surrounds the wearer with an envelope of pressurized air. It is more comfortable than the partial pressure suit and gives better protection. Problems arise in ventilating the full pressure suit and in removing water vapor.

G-SUITS.—The increased G-forces built up in flight are usually positive. Negative G-forces occur only occasionally, such as when an aircraft goes from level flight into a sudden dive. When the G-forces are negative, the blood rushes to the head, and the pilot may experience **red-out.** Negative G-forces as low as 2.5 to 3.5 G can be fatal.

After Dr. James Henry completed work on the partial-pressure suit, he remained at Wright Field to collaborate with Dr. Otto

Figure 37. Partial pressure suit. This kind of suit is pressurized in parts, or segments. The bottom layer of the suit is a large bladder inflated to provide counterpressure for most of the body. Additional counterpressure is provided by inflated capstans. Note the capstans extending along the pilot's arms, thighs, and legs.

Gauer, a renowned German authority on the circulatory system, to find out how pilots might be protected against negative G-forces. From experiments with animals in the centrifuge, Doctors Henry and Gauer discovered that fatalities from excessive negative G-forces resulted from hypoxia, not from brain hemorrhage, as had been supposed. Under the stress of negative G-forces, the blood rushing to the pilot's head caused swelling of veins. This swelling cut off the supply of oxygen to the throat and lungs, resulting in choking and severe hypoxia. When death was shown to be caused by hypoxia, the way was opened for providing protection.

Today pilots have some protection against negative G-forces by being supplied with adequate oxygen in a pressurized cabin, backed by an oxygen mask or a pressure suit. Pressurized helmets may offer enough counter-resistance to the increased blood flow in the head to raise the pilot's tolerance of negative G-forces by 2 G.

Another means had to be found to protect the body against positive G-forces. Doctors Henry and Gauer found that if an adequate supply of blood flowed from the pilot's heart to his eyes and brain, he would not black out. Based on this finding, the G-suit was developed.

The modern G-suit resembles a pair of cutaway nylon trousers or cowboy chaps (Fig. 38). The trousers have bladders positioned so that they fit at key points on the body. A small bladder is placed at each thigh and one at the calf of each leg, and a larger bladder is spread across the abdomen. The bladders are connected to a compressed air system. In normal flight the bladders lie flat, but as soon as the aircraft goes into a maneuver and the G-forces reach a positive 2 G, air is automatically released from the compressed air system and inflates the bladders. As they expand, the bladders press tightly against the pilot's body, causing the blood vessels in the lower extremities to constrict and keep the blood from pooling. This action forces the blood toward the pilot's head, maintaining the flow of blood between the heart and the eyes and brain.

The G-suit is worn either over or beneath the standard flying clothing. It may be designed to be part of the pressure suit for pilots flying high-performance aircraft, as noted earlier. The G-suit can give a pilot enough protection to increase his tolerance to positive G-forces by 2 G.

At the same time that researchers were developing the G-suit and other protective clothing for fliers, other researchers were trying to develop a pressurized cabin. They wanted to pressurize

Figure 38. A G–suit. This is a pair of cutaway trousers like those shown above. The G-suit may be worn outside the flier's suit, or it may be part of the suit.

the entire cockpit, not just the area immediately surrounding the pilot's body.

Pressurized Cabins

The pressurized cockpit, or the **pressurized cabin,** as it is generally known, took many years to develop. Many difficult problems had to be solved before a pressurized cabin was possible. Although the US Army Air Corps conducted its first experiment on such a cabin as early as 1920, the first American-built pressurized cabin did not appear until 1937 with the XC-35 research aircraft. The first American pressurized airliner, a Stratoliner, carried passengers in April 1940.

The pressurized cabin meant a real breakthrough in meeting the human requirements of flight at high altitudes. It represents a triumph of both medical and engineering knowledge. To develop the pressurized cabin, researchers drew upon the store of knowledge of flight physiology that had accumulated since the early balloonists and the French physiologist Paul Bert performed their experiments. Bert laid the foundation for the pressurized aircraft with his studies of pressure altitudes.

With the pressurized cabin, pilots and passengers now have more security during flight. If the pressure altitude of the cabin can be kept low enough, the occupants are protected against both hypoxia and decompression sickness, as well as expansion of trapped gases and most of the discomforts caused by sudden changes in pressure during flight. Further, the pressurized cabin can be maintained at a comfortable temperature even at very high altitudes.

PRESSURE DIFFERENCE AND STRENGTH OF STRUCTURE.—From an engineering standpoint, one of the most difficult problems in producing a pressurized cabin is to make the walls of the aircraft strong enough to withstand the difference in pressure between he atmosphere in the cabin and that on the outside. At lower altitudes, this difference in pressure, or the **pressure differential,** as it is called, need not be large, but as the aircraft flies to increasingly higher altitudes (and the need for a pressurized cabin becomes greater), the pressure differential becomes greater.

With a larger pressure differential, it is necessary to have stronger cabin walls to withstand the pressure across the walls. If, for example, the pressure of the atmosphere inside an aircraft cabin were kept at sea level pressure (14.7 psi) as the pressure on the outside of the aircraft approaches zero, the pressure differential would approach 14.7 psi. This represents a pressure of one ton on each square foot of wall space, including canopies, doors, and windows. To withstand such a tremendous pressure would require an aircraft structure too heavy to fly. Fortunately, man is able to tolerate a reduced-pressure environment.

If a pressure altitude of 8,000 to 10,000 feet is used instead of sea level as the lower limit, then the pressure differential across the walls of the aircraft cabin is greatly reduced. With a cabin pressurized to the 8,000-foot level, aircraft can fly at 40,000 feet to 45,000 feet with a maximum pressure differential of 8 to 9 psi. Most jet passenger aircraft are designed to operate at this pressure level. Recently, however, there has been a tendency for aircraft designers to use a higher pressure differential for passenger aircraft, permitting them to fly at the high cruising levels with a cabin pressurized to an altitude of 5,000 to 6,000 feet. Improvements in metals make possible stronger and lighter aircraft structures that can support larger pressure differentials.

Most high-performance military aircraft have less pressure in their cabins in order to keep the aircraft lighter in weight and allow more maneuverability, as well as to guard against the danger of decompression as the result of enemy fire. Military aircraft going to very high altitudes usually operate with a maximum pressure differential of about 5 psi. Therefore, at the highest flight altitudes, the cabin of such aircraft is at a pressure altitude of about 25,000 feet. At this level supplemental oxygen is needed to prevent hypoxia, but there still is protection against decompression sickness. Combat aircraft are equipped with an override control that makes it possible for the pilot to reduce cabin pressure if there is danger of being struck by enemy fire. In this way it is possible to reduce the hazards of decompression.

MAINTAINING THE CABIN ATMOSPHERE.—Other problems had to be solved in keeping the atmosphere within the cabin constant. The atmosphere must have excessive water vapor removed, it must be free of contaminants, and it must be kept at a comfortable temperature. The problems of keeping the cabin free of noxious gases and vapors are described in Chapter 1. The special problems of the space cabin are discussed further in the next chapter on spaceflight.

Surprisingly enough, one of the first problems encountered in pressurizing the cabin was overheating. Even when the outside temperature is a frigid −67 degrees F., the cabin tends to heat rapidly as air is drawn in from the outside and compressed. Improvements in air-conditioning equipment have helped to keep the cabin temperature constant.

CONVENTIONAL PRESSURIZED CABINS AND SPACE CABINS.—All aircraft cabins are pressurized in the sense that the air inside the cabin is under greater pressure than that of the ambient atmosphere. Up to 50,000 feet, or the lower limits of space-equivalent conditions, a cabin is usually pressurized by drawing in air from the outside and compressing it. This is a **conventional pressurized cabin** (Fig. 39). Above 50,000 feet the air from the outside must be sealed off, and the cabin is pressurized by making use of a supply of oxygen or other gas carried on board. Such a cabin is called a **space cabin** (Fig. 40).

In the space cabin the supply of gas for the artificial atmosphere is limited, and the gas must be kept from leaking. When large quantities of oxygen are needed for supplying the atmosphere for a space cabin, a converter system is used. The system provides for storing liquid oxygen (LOX) under pressure and then converting it into a gas for use. Handling oxygen on board aircraft at first presented difficult problems for engineers. Liquid oxygen must be kept at an extremely low temperature (about −297 degrees F.) to keep it from changing into a gas during storage. When converted into a gas for use, the liquid oxygen expands enormously (about 860 times).

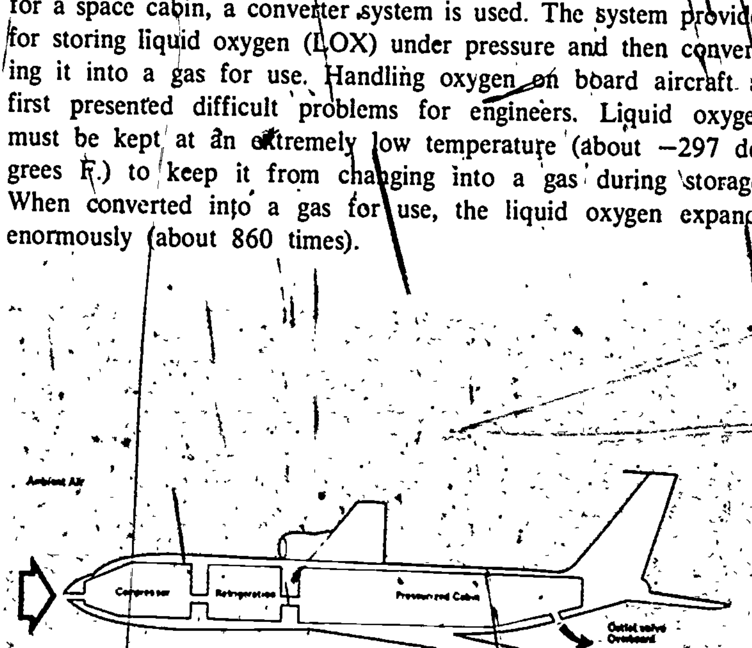

Figure 39. Operation of a conventional pressurized cabin. Air from the outside is drawn inside, compressed, and refrigerated. The atmosphere is kept fresh by dumping the stale air overboard and taking in fresh air.

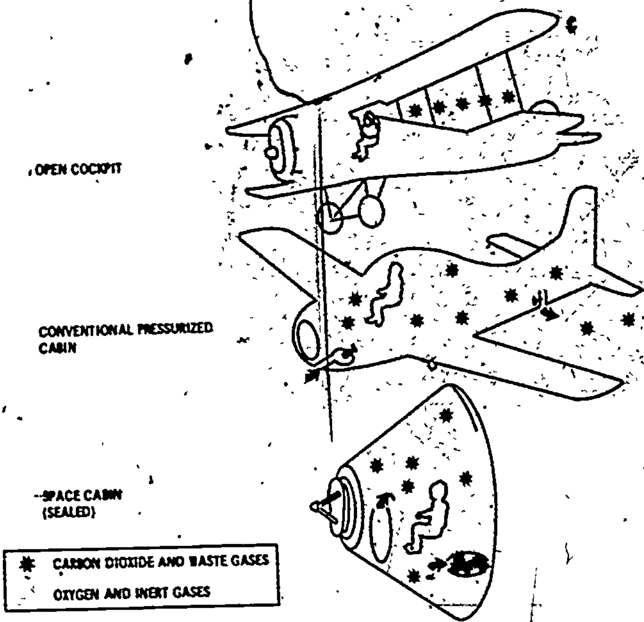

Figure 40. Difference between an open cockpit, a conventional pressurized cabin, and a space cabin. The conventional pressurized cabin is partially sealed; the space cabin is completely sealed.

HAZARDS OF DECOMPRESSION.—With both the space cabin and the conventional pressurized cabin, the greatest hazard lies in the possibility of rapid decompression at altitude. Military aircraft are in more danger of decompression, as they may be hit by enemy fire. The speed with which decompression takes place depends primarily upon the size of the aircraft and the size of the opening. If decompression is rapid and the aircraft is flying at a very high altitude, the pressurized atmosphere of the cabin explodes outward with a loud bang. The cabin becomes filled with dust, fog, or flying debris. Persons sitting near openings are in danger of being blown out if they are not firmly secured with a seat belt. The occupants of the cabin are left in a dazed condition. The greatest danger from rapid decompression is from hypoxia, as explained in Chapter 1. Fortunately, the victims of rapid decompression can survive if they are supplied emergency oxygen and the pilot can land without delay.

In general, the number of rapid decompressions has been quite small over the years even in military aircraft. Jet transports and high-performance military aircraft have proved to be structurally sound.

Combat pilots face other dangers than those from rapid decompression, however. As aviation progressed, it became apparent that some new means had to be found to help combat pilots escape from their aircraft when it went out of control.

Escape Equipment

When aircraft flew at relatively low altitudes and speeds, a pilot could escape from his aircraft simply by bailing out and making use of his parachute. When aircraft began traveling at high rates of speed, the G-forces increased sharply, and the pilot had difficulty first in forcing his way out of the aircraft and then in clearing the aircraft structures. For escape from high-performance aircraft, the military pilot now has an ejection-seat system. But whether a pilot makes an unassisted or an assisted escape, he uses a parachute for making his descent to the ground.

PARACHUTES FOR BAILOUT (UNASSISTED ESCAPE).—Pilots who fly in slow aircraft depend upon parachutes for **bailout** in an emergency The person making the escape simply releases the canopy of the aircraft or opens the door and jumps over the side, using his parachute to bring him safely to the ground. Combat crew members are taught how to "hit the silk," or use their parachute. Noncombat crew members may be required to wear parachutes during dangerous missions.

In October 1922 the first American life was saved by a parachute when Lt. Harold Harris, a US Air Corps test pilot, made a safe bailout. Since that time the parachute has saved thousands of lives. The parachute has been improved somewhat and better techniques developed for its use, but it remains essentially unchanged.

The **parachute** is made up of three basic parts: the canopy, the pack, and the harness (Fig. 41). The **canopy** is the large umbrella-like structure that fills with air and supports the pilot as he floats to the ground. Today the canopy is made of nylon rather than silk. Nylon is stronger than silk and produces less shock upon opening. The canopy is pulled from the pack by a small spring-loaded pilot chute, which first catches the airstream. The nylon **parachute pack**, the package in which the parachute is folded for storage, also encloses the **parachute harness**. The harness is a system of nylon webbing used to secure the wearer to the suspension lines of the canopy. Part of the harness is the sling in which the wearer rests as he descends. The sling is attached to the risers, the lines the pilot uses to guide the parachute as it

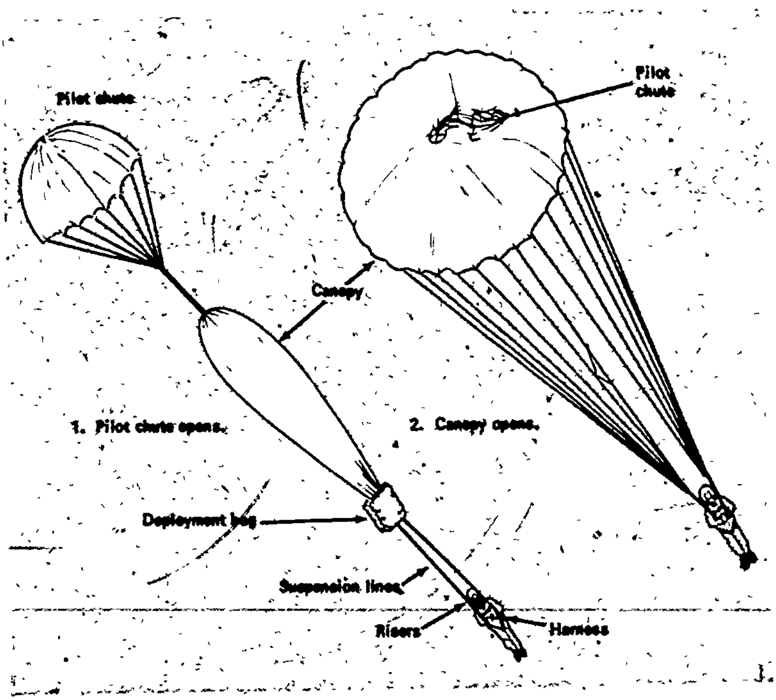

Figure 41. Deployment of a parachute. The small pilot chute opens first and then the large canopy. The user is fastened into the parachute harness. This is attached to the risers. The risers can be used to guide the parachute in landing.

nears the ground. The risers, in turn, are attached to the suspension lines of the canopy. After the parachute has brought the pilot to the ground, he falls, rolls over on his back to hold the parachute lines steady, and then releases the canopy to keep from being dragged along the ground.

When a pilot decides to abandon his aircraft, it is important that he make the decision and bail out while he still has sufficient altitude. With a modern parachute, the shock of opening is not severe, but the shock increases with altitude. The best minimum altitude for opening the parachute is about 1,000 feet above the ground, but safe openings have been made at lower altitudes. When casualties have occurred, they have most often been caused because the pilot was too close to the ground when he attempted to open his parachute.

When American pilots first tried to escape from high-performance aircraft during World War II, they had difficulty in getting out of the aircraft so that they could make use of their parachute. What was needed was some device to propel them away from the aircraft.

EJECTION EQUIPMENT (ASSISTED ESCAPE).—Today combat pilots in high-performance aircraft usually have their parachute fitted into the **ejection-seat system.** To build a practical ejection-seat system, engineers had to have a whole series of precise data about how the body is affected at the time of escape. Engineers had to know, for example, how much a man can stand in terms of G-forces, windblast, and oxygen deprivation. How much explosive force is needed to fire a man fast enough and far enough to clear the aircraft and still not injure him?

The Germans were the first to collect data that made ejection seats possible, and their pilots used such equipment for escaping from disabled aircraft during World War II. When the war was over, an American team headed by Dr. William Lovelace II, visited Germany and Sweden to obtain data on the ejection seat. The first American ejection seat was built from a German model. The first live American ejection was made by Sergeant Lawrence Lambert over Wright Field in 1946. In the next ten years 1,897 ejections were made by American pilots. Of this number about 81 percent were successful.

The ejection seat has been steadily improved, and changes in it have been made to keep up with advances in flight. One of the Americans best known for basic research on ejection equipment for use in high-speed aircraft is Dr. John Paul Stapp (1911-), now a retired Air Force colonel. Many pilots have attributed their lives to the equipment developed as a result of Stapp's work. Stapp, who gave his name to the measure of jolt force, wanted to find out more about the high G-forces that pilots encounter as they eject from high-speed aircraft. The doctor is especially known for the runs he made on the rocket-powered sled at Holloman AFB, New Mexico (Fig. 42).

At present the Air Force makes use of two types of ejection seats. One type ejects upward and the other downward (Fig. 43). Both types of ejection seats are based upon the catapult principle, the principle for propelling aircraft from carriers. The ejection seat is equipped with explosive cartridges that propel the seat along a track and out and away from the aircraft. The seat is usually equipped with harnesses, guard rails, a footrest, and a headrest that hold the pilot's body firmly in position to withstand the large G-forces. After the seat has cleared the aircraft and descends to a safe altitude, the pilot separates automatically from the seat (Fig. 44). Later his parachute opens automatically to bring him safely to the ground. These automatic features protect the pilot should he become unconscious. Some modern ejection seats are inclosed in a capsule to protect the pilot against windblast.

Figure 42. Colonel Stapp, being prepared for run of rocket powered sled. His arms and legs were strapped down to protect him against large G-forces.

Since pilots of high-performance aircraft may have to eject at very high altitudes, one of the essential features of ejection equipment is the **emergency oxygen cylinder,** or bottle, that the pilot takes with him as he leaves the aircraft. If the pilot escapes at altitudes above 50,000 feet, he is protected by a pressure suit and the oxygen bottle. If the pilot is flying below 50,000 feet, the Air Force has an emergency oxygen bottle that can be used in free fall. When actuated, it automatically delivers oxygen under pressure for about 10 minutes. This is long enough for safe descent to lower altitudes.

At first tumbling was one of the most serious problems faced by pilots who ejected at high altitudes. When a pilot ejects in the stratosphere, he does not want his parachute to open too soon, as he would descend too slowly. Then he would suffer from prolonged exposure, and the oxygen supply in his emergency bottle might be exhausted before he reached an altitude that could support breathing. Therefore, a pilot who ejects at a high altitude must first go into free fall. While in free fall, he might be tumbled so violently as to become unconscious. Pilots can keep their bodies oriented and prevent tumbling during free fall by making movements with their arms and legs.

Although pilots attempt to eject at high altitudes, most fatalities have occurred because the pilot was unable to get out in time and the aircraft went into a steep dive. Then the pilot could not eject in time to separate from the seat and open his parachute. To increase the chances of survival at low altitudes, the Air Force makes use of the One and Zero System, which is attached to the parachute. This system can override the one-second delay built into the automatic opening device on the parachute.

To give the pilot an even better chance of survival on low-level ejections, the Air Force is developing what is known as the Zero-Zero System (zero altitude and zero airspeed). This system is provided with a rocket seat and drogue parachutes, which work somewhat like the escape tower on the Apollo spacecraft. If the pilot does not eject soon enough to make a safe parachute landing,

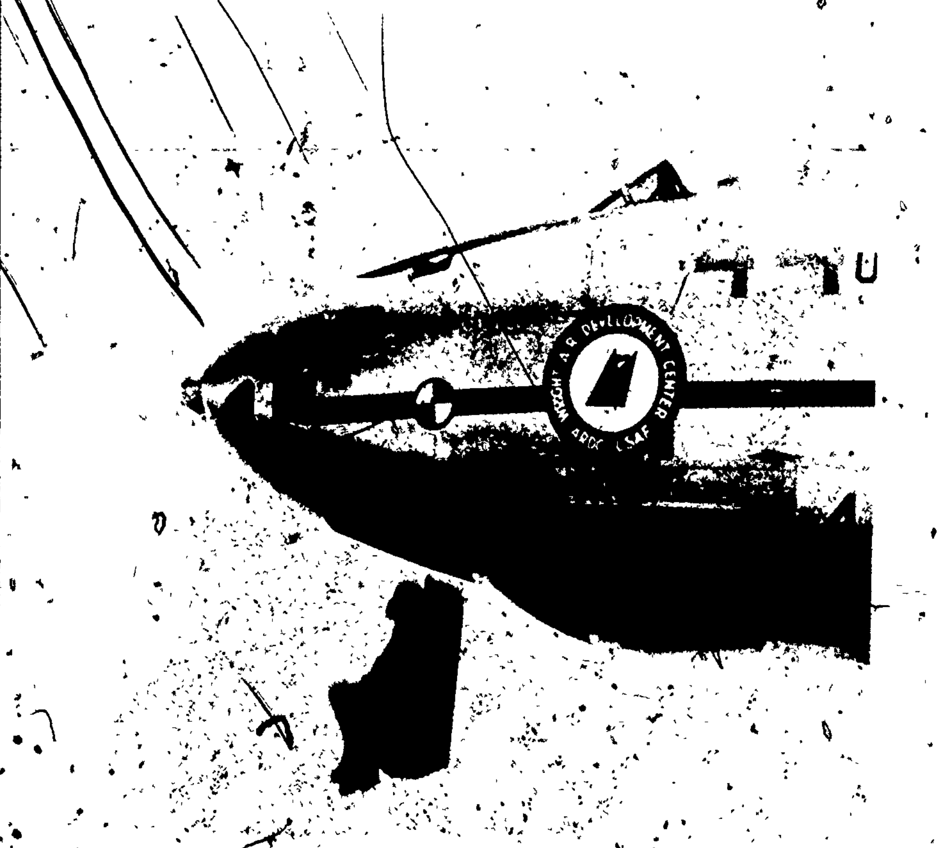

Figure 43. Crewman ejecting downward from a B–47 bomber. The crewman was propelled out of the bomber when he pulled a ring on the seat.

he is to be rocketed up to an altitude that allows for opening the parachute and making the descent. Research continues on escape systems that will be even more reliable than those presently used: Rocket seats, improved capsules, and even miniature independent flying cockpits are being developed.

To be able to use escape equipment and other protective devices and to look after the safety of crew members and passengers, a pilot must have special training. Learning safety procedures is part of every pilot's training.

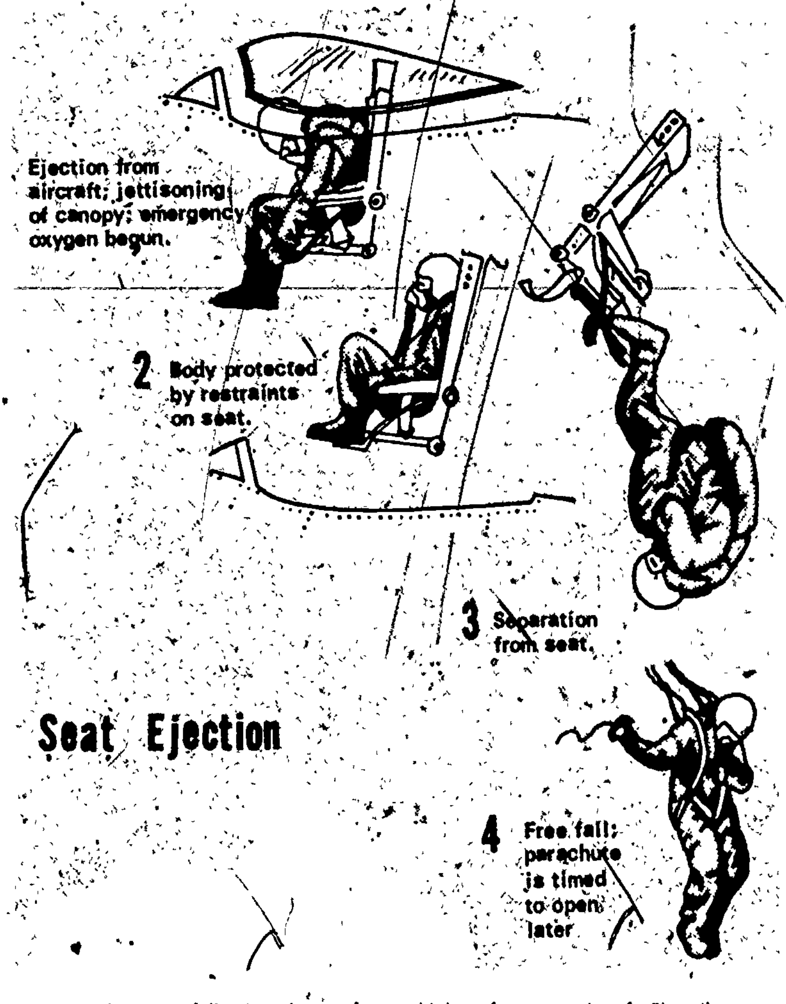

Figure 44. Sequence following ejection from a high performance aircraft. The pilot goes on emergency oxygen as he ejects. An automatic timing device causes the parachute to open at a safe altitude.

TRAINING PROGRAMS

A pilot who flies a modern high-performance jet is likely to take some kind of training at intervals throughout most of his career. The initial training, which lasts about a year, simply qualifies the beginner to be a pilot. The beginning civil pilot must fly many hours as a second officer before he is eligible to become the first officer and then the captain, or command pilot, of a large airliner.

In any kind of flying there is no substitute for experience. Whenever new equipment is introduced, the pilot is given special training in its use. A pilot who is to take over a new kind of aircraft must first undergo **transitional training,** or changeover training.

If continual training is needed by the civil pilot, it is needed even more by the military pilot. The military pilot is likely to fly several different kinds of aircraft and perform a variety of duties during his career.

Military Programs

The US Army, Navy, and Air Force each conducts a separate flight training program. The Army and the Air Force use civilian contract schools for part of the training, mostly in the primary phases of both regular fixed-wing and rotary-wing aircraft (helicopters). Each service conducts its own advanced and tactical training. The Navy continues to train its own pilots in all phases of the program.

The Air Force beginning flight training program for American pilots, known as Undergraduate Pilot Training (UPT), is changing constantly to meet the needs of the Air Force and to make use of improved training methods. At present Air Force Undergraduate Pilot Training is conducted at Air Force bases throughout the South and the Southwest. All of the training except for survival training is carried through at one base. For the survival training all student pilots go to Fairchild AFB, Washington. Trainees stationed at Fairchild spend seven days in the nearby forest. During this time they learn how to survive in hostile territory.

The airstrips at the Air Force training bases hum with activity. All day long jet trainers take off and land as prospective pilots learn how to handle them. Two jet trainers are used: the T–37 "Tweetie Bird" and the T–38 Talon. The T–37, the subsonic trainer (Fig. 45), is used by the student pilots after they have completed primary work with the propeller-driven trainer. The

Figure 45. Student pilot after flight in subsonic T-37. The instructor is showing the student how to prepare a log of his flight.

T-38 (Fig. 46) flies at supersonic speeds. Both jet trainers are highly maneuverable and can be fitted with equipment used in combat aircraft. A prospective Air Force pilot must have about 16 hours of flight in the propeller-driven trainer, about 90 hours in the T-37, and about 100 hours in the T-38.

A valuable part of flight training recently added is parasail training. Formerly it was difficult to give the beginner a realistic feel for parachute jumping without exposing him to some danger. Now a trainee practices in safety on the parasail (Fig. 47). This is a parachute pulled aloft by a line attached to a truck or boat. After the trainee goes up 300 to 400 feet, he is cut loose and descends on his parachute.

Besides the survival and flight training itself, the Air Force candidate takes physical education and has some 600 hours of classroom instruction in such subjects as aerodynamics, navigation, weather, instrument flying, and general officer training. The entire program for beginning Air Force pilots lasts about 52 weeks. It is estimated that the Air Force spends about $90,560 for each trainee who graduates from the program.

Air Force navigators are trained at Mather AFB, California, where they learn advanced techniques for navigation. Since these prospective navigators will become part of a regular flight crew, they are required to complete safety and survival training equivalent to that given pilots.

Figure 46. Student pilots learning about the supersonic T-38. This is the advanced jet trainer.

Figure 47. Parasail demonstration by Astronaut Alan Shepard. At this point Shepard is ready to be hoisted aloft. Student pilots learn how to use a parachute by practicing with the parasail.

Navy and Marine pilots and navigators go through a similar program of hard work and study. Prospective pilots in the Navy and Marine Corps are assigned to a wing of the Naval Air Training Command that is located at Pensacola, Florida.

Navy and Marine Corps pilots also undergo training to qualify them for flight from a carrier. A Navy carrier operates in the Gulf of Mexico off the coast of Florida for this type of training. Both a propeller-driven aircraft, the T-28, and a jet, the single-engine T-2 Buckeye, are used. Students make "arrested" landings (complete stops) and touch-and-go landings. Before they complete their work, they are able to come in and land on the carrier as part of a flight formation.

The science of flight training as developed by the military services became the basis for civil flight training.

Civil Programs

Pilot training can be obtained at most airports from flying schools or from individual instructors. In addition, some colleges and universities offer pilot training as part of their regular curriculum. Training civil pilots is a large operation. The number of civil pilots being trained has increased steadily. By 1973 there were some 750,000 certified civil pilots. The Federal Aviation Administration (FAA), the agency that certifies civil pilots, also supervises their training and approves flight courses and flight instructors.

A **flight instructor** is an expert in the art of flying and a professional teacher as well. He is skilled in coordinating controls on an aircraft, but he also understands the latest methods of teaching. A flight instructor must meet specified requirements and be licensed by the FAA. He must hold a pilot's certificate for the kind of aircraft he is instructing his students to fly, he must have at least a commercial pilot certificate, and he must pass a test on the fundamentals of flight instruction. Much of the reward that a flight instructor gets from his job is in seeing raw beginners become good pilots under his direction.

With the growing demand for civil pilots, the airlines can no longer fill their needs by recruiting pilots trained by the military services. They must obtain many of their pilots from civil flight training programs. The airlines do not give beginning training for pilots, but they provide their own training for pilots who are promoted in rank or who are to fly a new kind of aircraft or use new equipment.

The major airlines have now completed the program for transitioning their pilots from propeller-driven aircraft to jets. During this training many experienced pilots practically had to learn to fly all over again. Now the airlines are training pilots to fly jumbo jets. In transitioning to jumbo jets, the airlines are making greater use of flight simulators than ever before. Flight simulators, first developed by the military services, are now used in both military and civil programs for training pilots.

FLIGHT SIMULATORS

A **flight simulator** is an apparatus that simulates, or gives the effect of, one or many conditions of flight. In the broadest sense, flight simulators include most flight training devices. The Air Force uses more than 300 flight simulators for training pilots. Of this number only somewhat more than 40 are advanced simulators that reproduce the motions of flight and are controlled by computers. Actually there are two principal kinds of flight simulators. stress devices and mockups giving the feel of flight.

Stress Devices

The low-pressure chamber, the centrifuge, and other devices originally used for studying the stresses of flight are now being used in pilot training.

LOW-ALTITUDE CHAMBER.—An important part of a pilot's training is learning to "fly the chamber," or to take simulated flights to altitude in the low-pressure chamber (Fig. 48). The trainee takes these flights after he has finished his physiological training but before he attempts actual high-altitude flights. Seasoned military aircrew members go back to the altitude chamber at specified intervals to find out if their reactions to hypoxia have changed.

In the chamber flights the reduced pressures are real, and the same oxygen equipment is used as in actual flight. All that is different is the fact that the sealed chamber rests on the ground, and that observer and technicians are stationed in and around the chamber to help trainees and prevent accidents.

To get the feel of altitude, you might go with Air Force trainees on an imaginary flight to 43,000 feet. This would put you far up in the physiological-deficient zone where pressure breathing is required Before trainees make this flight, they have made at least one flight in the chamber to learn about using the oxygen mask. A plan for the present trip has been posted in advance.

Figure 48. View through window showing students making a "flight" in the altitude chamber. The technicians at the controls can bring the students down from altitude in an emergency.

Although the trainees have made a previous flight in the chamber, the instructor briefs them on the effects of reduced pressure at altitude. He also places in plain sight in the chamber a partially inflated balloon attached to a jar. You are to watch the balloon inflate more as pressure in the chamber falls. This will help you understand what is happening to your body. The instructor reminds you about the dangers from trapped gases. He tells you that you must permit trapped gases to escape from your stomach and intestines by belching or passing flatus. He also cautions you about the bends, the chokes, and other forms of decompression sickness. You need not be concerned about decompression sickness until you reach an altitude above 30,000 feet. If you should get the bends or if any other emergency should develop, you are to use prearranged hand signals to let the technicians know you need help.

A technician then gives you a pressure-demand oxygen mask and an emergency oxygen cylinder, or bailout bottle, and you check these to see that they are in order. You try on the oxygen mask to make sure it fits. You will need the bailout bottle because you are to make a simulated free fall after reaching 43,000 feet. Once the instructor makes sure that both you and the equipment are ready, you don the oxygen mask and begin to breathe pure oxygen. The chamber door is left open to keep the pressure outside your body at sea level.

Before a pilot goes to high altitudes, either in the chamber or in actual flight, he first breathes pure oxygen at sea-level pressure. The process, known as **denitrogenation,** drives most of the nitrogen from the body tissues into the bloodstream. From here the nitrogen is carried to the lungs and exhaled. Getting most of the nitrogen out of the body before ascent to altitude helps to prevent decompression sickness at altitude.

After denitrogenation is completed, the instructor gives the signal to begin ascent. The door to the chamber is closed, and the air begins to hiss as it leaves the chamber. You ascend to 5,000 feet while your ears pop. Then you make the descent to sea level again, clearing your ears successfully. This preliminary ascent is a safety check. If any of the trainees should have trouble clearing their ears because of colds or congestion, this is the chance for them to leave the flight. Everyone is all right. You begin the ascent once more.

At 5,000 feet you remove the safety pin from the emergency oxygen cylinder. While you are still within the physiological zone, the instructor has you practice adjusting the settings on the oxygen regulator (with the new type system the pressure is adjusted automatically).

During the practice period the instructor also briefs you on **pressure breathing.** As you continue the ascent you begin to experience the strange process for yourself. Before reaching 30,000 feet, you adjust the setting for the regulator to "Safety," and you begin to breathe under pressure. Then your whole breathing process is reversed. You are breathing *out* instead of *in*. As you continue the ascent, you concentrate on breathing slowly to prevent hyperventilation, or overbreathing. The oxygen is cool, but you are perspiring from the effort to control your breathing. The pressure outside your body seems to be almost entirely gone now, and you begin to wonder if you are getting the bends. You are grateful that pain in your joints does not develop. Finally you are free of trapped gases also. Your ears clear, and the pressure in your stomach is relieved. By the time you near 43,000 feet, the pressure of the oxygen delivered to the mask is tripled.

Finally, you reach the awesome height of 43,000 feet. You remain at this altitude for moments only, but they seem endless. You wonder what might happen. You do not have too much time to think about the dangers of decompression because you have to concentrate on breathing. At last the signal is given to descend. You activate the emergency oxygen cylinder and begin the simulated free fall.

As you reach 25,000 feet, you feel the tension once more. At this altitude you are to take off your oxygen mask to find out more about your own personal symptoms of hypoxia. You have tried breathing at altitude without an oxygen mask before, but you are not sure what will happen this time. You work in pairs for the test. You are to take off your mask first, and your partner will observe you. When the signal is given, you remove your mask. You hear someone ask you to write your name. That is easy enough—at first. You write your name twice. Then you become dizzy, and the pencil wanders (Fig. 49), but you keep trying. The effort is becoming too much for you. Everything begins to dim before your eyes. The next thing you realize, you have

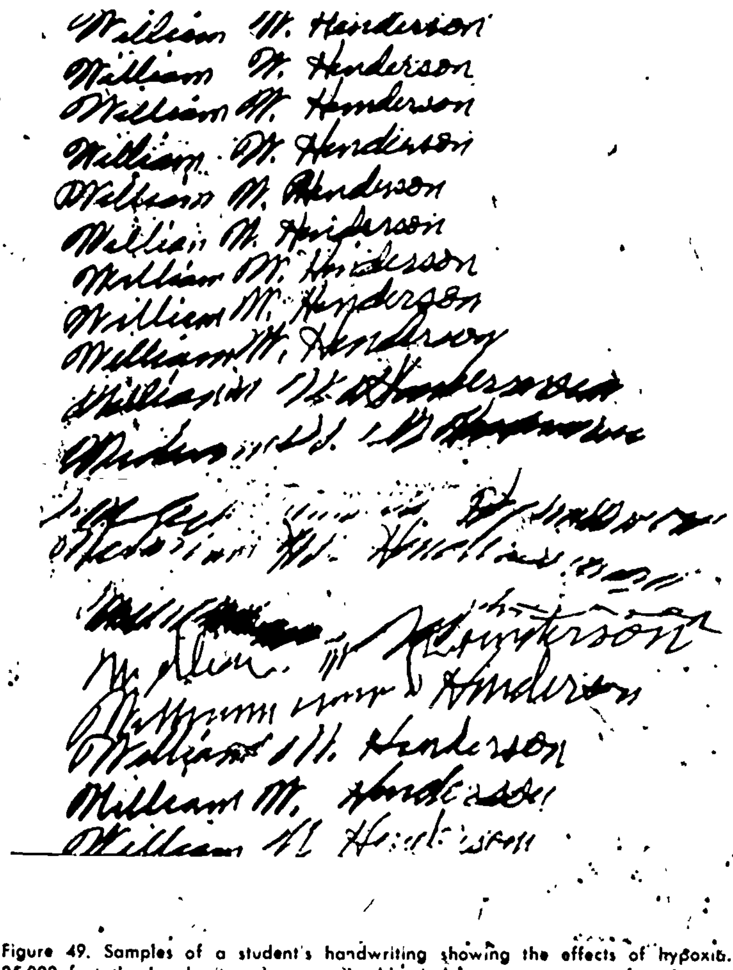

Figure 49. Samples of a student's handwriting showing the effects of hypoxia. At 25,000 feet the handwriting became illegible. It began to improve after the student replaced his oxygen mask

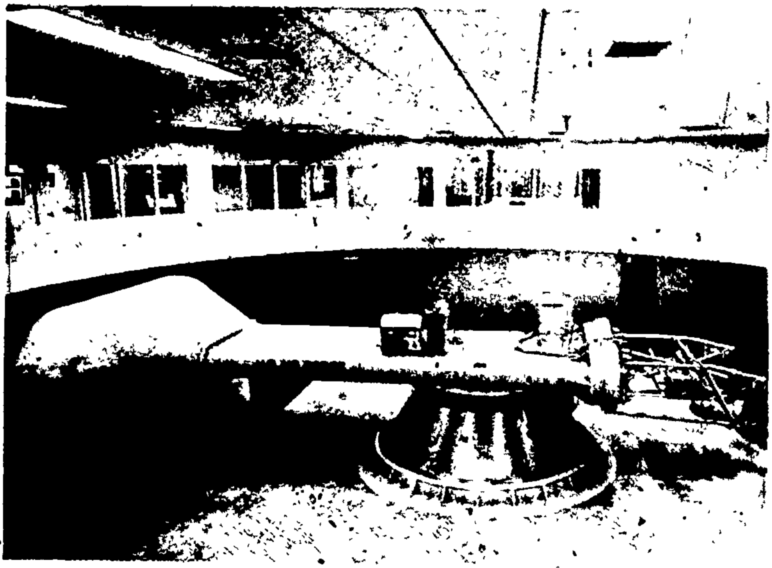

Figure 50. Human centrifuge. A trainee spinning on this centrifuge is subjected to G–forces similar to those experienced by the pilot of a high-performance aircraft. The centrifuge can be stopped if the trainee is in danger.

your mask back on, and you are breathing pure oxygen. Your partner has helped you. When he takes his turn, he is able to breathe for a longer time without his mask. You know that you must learn to act even more quickly than he does in an emergency because your time of useful consciousness is shorter. You are reassured, nevertheless, because you are learning more about hypoxia, and you know that the test will soon be over. The instructor gives the signal, and you are on the ground again.

Besides taking flights in the chamber, a military pilot might practice on the centrifuge during his training program.

HUMAN CENTRIFUGE.—A **human centrifuge** is made up of a gondola, or cabin, that is rotated at the end of a long arm (Fig. 50) A trainee in the spinning gondola feels increased G-forces like those experienced during flight.

Some of the large centrifuges, such as the Navy centrifuge at Johnsville, Pennsylvania (Fig. 51), create large G-forces, which quickly cause the subject to black out. The forces are controlled by an observer who can slow down or stop the centrifuge.

A trainee learns to cope with increased G-forces by practice on the centrifuge. In time he finds out what he can do to help keep the blood flowing from his heart to his brain and eyes as the G-forces mount. Pilots say that tensing the body, grunting, or

Figure 51 Large Navy centrifuge. This centrifuge at Johnsville, Pennsylvania, has a 50-foot arm. The trainee has biomedical instruments attached to him to tell how he is being affected by increased G-forces.

screaming help Such actions constrict the blood vessels and help keep the blood flowing against the resistance of positive G-forces.

OTHER STRESS DEVICES.—To familiarize them with other stresses of flight, prospective pilots may take workouts on a wide range of other stress devices.

One Air Force device used to train pilots is the Spatial Orientation Trainer (Fig. 52). It was developed by the Air Force School of Aerospace Medicine. This trainer has controls the pilot can manipulate to regain balance and orientation.

A device that helps prospective fliers become accustomed to the spinning and disorientation experienced in flight is the "biaxial stimulator," or the Coriolis chair (Fig. 53). This chair enables the trainee to spin in three different planes, just as the pilot does during the rolling, pitching, and yawing of his aircraft. With the help of the "biaxial stimulator," the prospective pilot learns how sensitive he would be to disorientation during flight and how quickly he would regain his balance.

The many different kinds of stress devices enable a pilot to learn how to cope with a great variety of flight stresses. A pilot also needs flight simulators that reproduce the total feel of flight.

Mockups Giving the Feel of Flight

When military aircraft began to fly, they were required to reach a speed of no more than 40 mph. One of the first Air Force pilots, Lt. Benjamin Foulois, received his flying lessons through the mail. Later, as aircraft began to fly faster and higher, there was a larger gap between knowing what to do to control the aircraft and actually being able to control it. Instructors went with prospective pilots when they attempted their first flights. To lessen the danger of crashing, the fledgling pilot kept the plane low. Learning to fly by the "grass-cutting method" was a step forward, but accidents were frequent nevertheless.

Figure 52. Spatial Orientation Trainer. This flight simulator helps a pilot learn how to maintain balance and orientation. It is especially helpful in teaching pilots to trust their instruments.

Figure 53. "Biaxial stimulator" or Coriolis chair. This chair tests balance and orientation. The subject has electrodes attached to his face. They record the amount of disorientation the subject experiences after being tilted.

Fortunately, when pilots had to be trained in large numbers during World War II, the first Link trainer was developed. This trainer, the first of the second kind of flight simulators, reproduced with remarkable realism many conditions of flight. Since that time many kinds of mockups have been developed to simulate the flight of particular aircraft.

With the aid of the simulator for a given aircraft, an instructor can give his students experience in flying that aircraft without leaving the ground. He can, for example, give them the opportunity for taking care of a cross wind, meeting an engine failure, or taking over when the cabin is depressurized. The beginner can try his hand at flying without the danger of crashing.

This second kind of flight simulator makes training much safer and more economical. The airlines would have to spend large sums of money to put jumbo jets into flight to give pilots the kind of transitional training that can be given more safely with flight simulators.

Civil pilots are enthusiastic about the sophisticated flight simulators that enable them to transition quickly to the newest aircraft. Such simulators have mockups that reproduce realistically the cockpit of the aircraft. They have all its controls, horns, and lights (Fig. 54). Instruments are controlled by a computer that is programmed to respond to the pilot's actions, just as the controls of the real aircraft do. In addition, the trainee sees the same kind of sights outside the cockpit. He would, for example, get a realistic view of the runway as he is simulating a landing (Fig. 55).

The engineers who have developed flight simulators for the newest aircraft have obtained some of their know-how from making trainers for astronauts. Flight simulators are used more in training astronauts than aircraft pilots, and the stresses of spaceflight are more severe than those of aircraft flight.

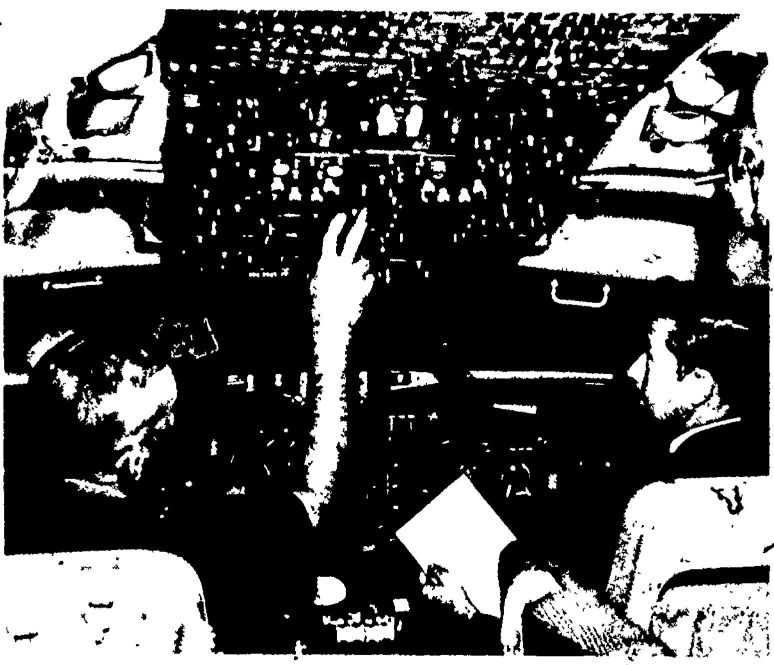

Figure 54. Cockpit view of the flight simulator for the 707 jet aircraft (American Airlines photo). This simulator realistically reproduces the cockpit controls and instruments of the aircraft.

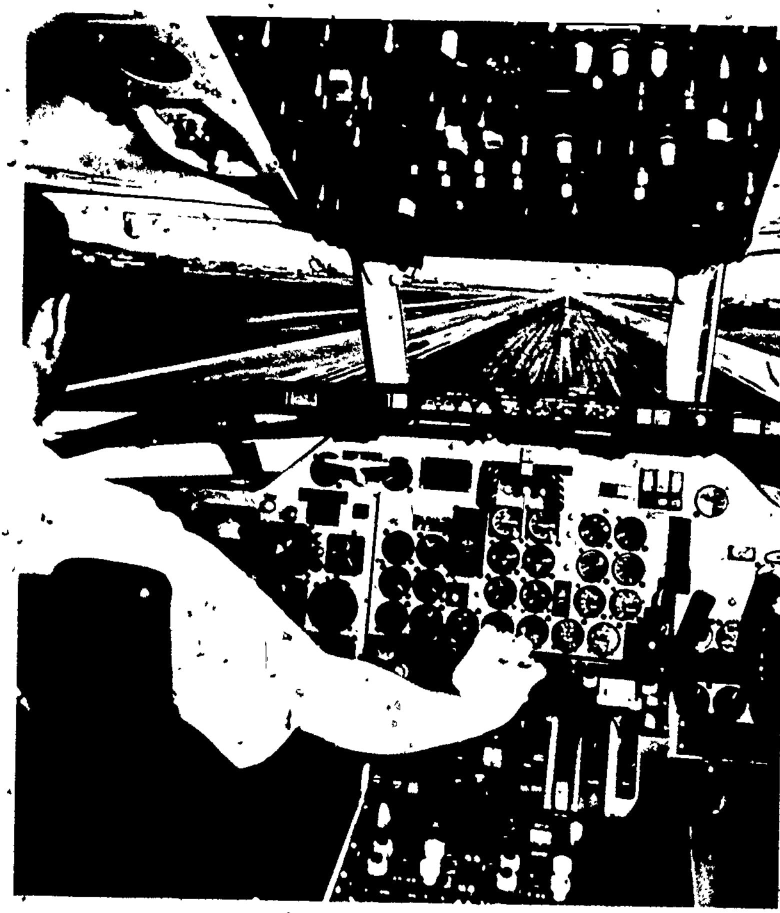

Figure 55. Pilot landing a 747 jumbo jet with the simulator (Delta Airlines photo). This realistic view of the runway is seen from the window of the cockpit simulator. The scenes outside the window change as the pilot manipulates controls.

TERMS TO REMEMBER

- oxygen breathing systems
- oxygen mask
- continuous-flow oxygen system
- demand oxygen system
- pressure-demand oxygen system
- pressure suit
- principle of layering
- partial-pressure suit
- full-pressure suit
- bladder
- capstans
- helmet
- red-out
- G-suit
- pressurized cabin
- pressure differential
- conventional pressurized cabin
- space cabin

bailout
parachute
canopy
parachute pack
parachute harness
ejection-seat system
emergency oxygen cylinder
transitional training
flight instructor
flight simulator
denitrogenation
pressure breathing
human centrifuge

QUESTIONS

1. What are the three kinds of oxygen breathing systems? What is the difference between them?
2. How is the principle of layering used in constructing pressure suits? What was the first successful pressure suit like?
3. What are the main parts of a pressure suit? What is the principal difference between the partial-pressure suit and the full-pressure suit?
4. How does the G-suit protect a pilot? When is it used?
5. Describe two problems that had to be solved before pressurized aircraft cabins were possible? What are the two kinds of pressurized cabins?
6. What are the principal parts of a parachute? How is the parachute used?
7. Explain how an ejection-seat system works. What is the purpose of the emergency oxygen cylinder?
8. What is meant by transitional training?
9. What kind of trainers do prospective military pilots learn to fly? What are some of the requirements that a military pilot must meet during his training?
10. How do civil pilots obtain their training? What requirements must a civil flight instructor meet?
11. Why are flight simulators important in training pilots? What is a human centrifuge? A low-altitude chamber?
12. What kind of training do the airlines give their pilots? What kind of flight simulators do they use?

THINGS TO DO

1. Demonstrate the use of an emergency oxygen mask like that found on commercial transports. Before a flight, the airline hostess explains to the passengers how they are to use the oxygen mask in an emergency. Make a similar demonstration. If you cannot borrow one of the masks, make a simple model of the mask for use in the demonstration. What kind of oxygen system is used for passengers on a commercial transport? Tell how the system operates. Why do the passengers need less oxygen than the crew members?

2. If you are located near an Air Force base, your instructor might arrange for a visit to the base to look over the flight clothing and equipment. Request that a technician demonstrate the use of the pressure-demand oxygen system.

3. Explain the operation of the partial-pressure suit. Your instructor may be able to borrow a suit for the demonstration. If this is not possible, use a diagram or a model of the suit. How is the principle of layering applied? What kind of protection does the partial-pressure suit give?

4. Explain the operation of the G-suit. Use a diagram or model. What happens when the bladders in the suit are inflated? How do they affect the flow of blood?

5. The parachute is the basis for all successful escape and recovery. It is used by aircraft pilots for a simple bailout or for an ejection. The astronauts also depend upon parachutes for their safe recovery. Use a diagram or model of a parachute to show the main parts. Explain the principal steps in making a descent and landing.

6. Demonstrate the operation of the ejection-seat system. Use a diagram or model of the seat to explain the sequence. What is the One and Zero System? When is it used?

7. If you are located near an Air Force training or research facility, your instructor might arrange for you to watch students make a simulated flight in the altitude chamber. Find out the purpose of the flight and the highest altitude reached. What did you observe about the reactions of the students? Did some of them develop hypoxia?

8. Describe a prospective pilot's experiences during training in the human centrifuge or on the Coriolis chair. Demonstrate the Coriolis chair, if possible, by using a spinning swivel chair. What is the purpose of the flight simulator you are describing?

9. Describe one of the sophisticated flight simulators used by the commercial airlines for training their pilots. What kind of training do the commercial airlines provide for their pilots?

SUGGESTIONS FOR FURTHER READING

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THIS CHAPTER explains how man has countered the stresses of spaceflight and how he has adjusted to routine living in space. The chapter first describes the stresses new to spaceflight (radiation, meteoroids, and weightlessness) and then some stresses of aircraft flight that become more severe in spaceflight (increased G-forces, heating, noise and vibration, and lack of atmosphere). Next the chapter explains the operation of the spacecraft's space cabin and the astronaut's space suit and tells how these are tied into the central environmental control system. Then the chapter describes the management of life support supplies and waste on board a spacecraft and tells how the astronaut adjusts to day-night cycles, how he is given medical monitoring, and how he meets mental stresses. Finally, the chapter outlines the measures taken to insure the astronauts' safety at launch and during flight. After you have studied this chapter, you should be able to do the following: (1) describe the three stresses new to spaceflight, (2) explain how three stresses of aircraft flight become more severe in spaceflight, (3) name the principal items of life support needed on a spacecraft and tell how these were provided on the Apollo spacecraft, (4) explain how doctors monitor the astronauts, and (5) name three measures taken to insure the astronauts' safety.

ONCE MAN HAD LEARNED how to put animals into orbit, he was ready to make a giant stride in advancing manned flight. After some sixty years of flight in winged aircraft, man rocketed into space. Pilots in the X-15 had traveled at record altitudes above 60 miles and at speeds of more than 4,500 mph. Astronauts traveled at altitudes above 100 miles and at speeds of more than 17,500 mph when they first orbited in space.

Man's progress into space represented a sudden advance not only in terms of altitude and speed but also in the whole manner of flight. As a result, spaceflight brought with it new and more severe flight stresses. Countering these stresses to survive and live in space called for even greater ingenuity than in advancing flight through the atmosphere.

SPACE ENVIRONMENT

As flight transitioned from the earth's atmosphere farther into the space-equivalent zone, some of the first problems encountered were not new but were more severe.

As man advanced into the space-equivalent zone, which extends from an altitude of 50,000 feet to 120 miles, the greatly reduced barometric pressure presented no new hazard. Men flying in aircraft above 50,000 feet had already learned how to protect themselves against lowered atmospheric pressure with a space cabin and a full-pressure suit.

Within the space-equivalent zone man had already encountered some increase in the intensity of radiation. At an altitude of about 20 miles, more cosmic rays are present than at the earth's surface because the atmosphere no longer is dense enough to screen out this radiation. Even more numerous are the secondary cosmic rays, which have formed as the primary rays collide with the earth's atmosphere. At this level are also found the shorter ultraviolet rays from the sun. The 20-mile limit marks the beginning of the gradual change of the flight environment from a gaseous to a **radiation environment** (Fig. 56).

The darkness and total silence of space begins at about 100 miles above the earth. Here there is not enough atmosphere to scatter light rays, and the familiar blue of the sky gives way to the jet black of space. This is the black expanse that the balloonists saw stretching above them as they reached the ceiling of their flight at more than 20 miles above the earth. In the darkness of space the stars, instead of twinkling, stand out as brilliant points of light, and the sun is a blinding sphere of light. There is no sound at this altitude because there is not enough atmosphere to transmit sound waves. Also, because of the lack of atmosphere, heat can no longer be transmitted by gas molecules but is gained or lost only through radiation.

At 120 miles above the earth the total space-equivalent zone begins. At this altitude there are not enough air molecules to create friction that would interfere with the orbiting of a spacecraft.

Meteoroids create another potential hazard for spaceflight. At orbital altitudes there is not enough atmosphere to burn up the meteoroids, or the particles of cosmic matter that travel about in space at great speeds. Closer to the earth these particles are burned up in the atmosphere.

From data received from satellites, man has already accumulated a body of knowledge about space. Scientists are continuing to study how new hazards, or stresses, of space might affect living matter.

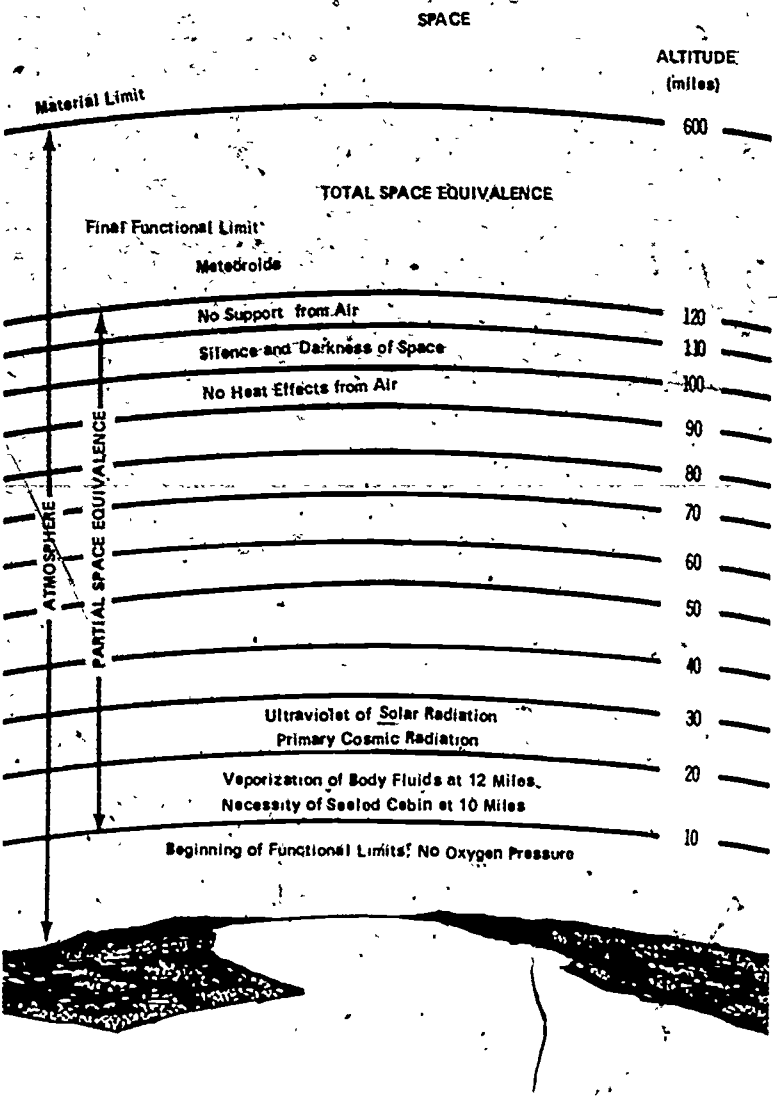

Figure 56 Space equivalent zone and space. At the lowest orbital altitudes (about 120 miles) astronauts find the total silence and darkness of space. At this altitude they are also exposed to some harmful radiation and to possible impact with meteoroids.

STRESSES OF SPACEFLIGHT

Three stresses are new to spaceflight: (1) radiation, (2) meteoroids, and (3) the condition of weightlessness. The first two of these stresses result from the space environment and the third from the nature of orbital flight. Other stresses of spaceflight are similar but more severe than those experienced in high-altitude flight in aircraft. Examples of such stresses are increased G-forces, heating, noise and vibration, and lack of atmosphere.

As man has progressed in spaceflight, he has gradually extended the time of flight under stress. For the astronaut, it is not a matter of merely spending so many hours aloft and then returning to the ground to take up routine living again. The astronaut thinks in terms of adjusting his living to the space environment, as well as controlling his vehicle under stress. Before you can fully appreciate the conditions under which the astronauts live and work in space, you must understand the stresses to which they are subjected.

Radiation

On earth man is protected against most of the radiations that come to him in all directions from space. There are two means of protection: the earth's atmosphere and the magnetosphere (the magnetic field of the earth) (Fig. 57). These reduce the intensity of the radiation that reaches the earth. When man goes into space and onto the moon, he leaves behind him the protection of the earth's atmosphere, and he may go beyond the magnetosphere also. When he does this, he is exposed to the entire range of natural radiations found in space. The moon has neither an atmosphere nor a magnetic field of its own to shut out, or repel, charged particles.

One of the most serious potential hazards to man in space is that from exposure to **ionizing radiation** (charged particles caused by an interaction with radiation). The astronauts can be protected against the intense nonionizing radiation—such as the glaring visible light rays, the infrared rays, and the ultraviolet rays—by the visors in their helmets, by their space suits, and by the wall of the spacecraft. Shielding can also be provided to protect the astronauts against the ionizing radiations in the electromagnetic spectrum, such as the X rays and the gamma rays. It is the ionizing radiation of the particle variety that presents the real danger to man in space.

The ionizing **particle radiation** in space is made up of: (1) solar-flare particles, (2) charged particles trapped in the Van Allen

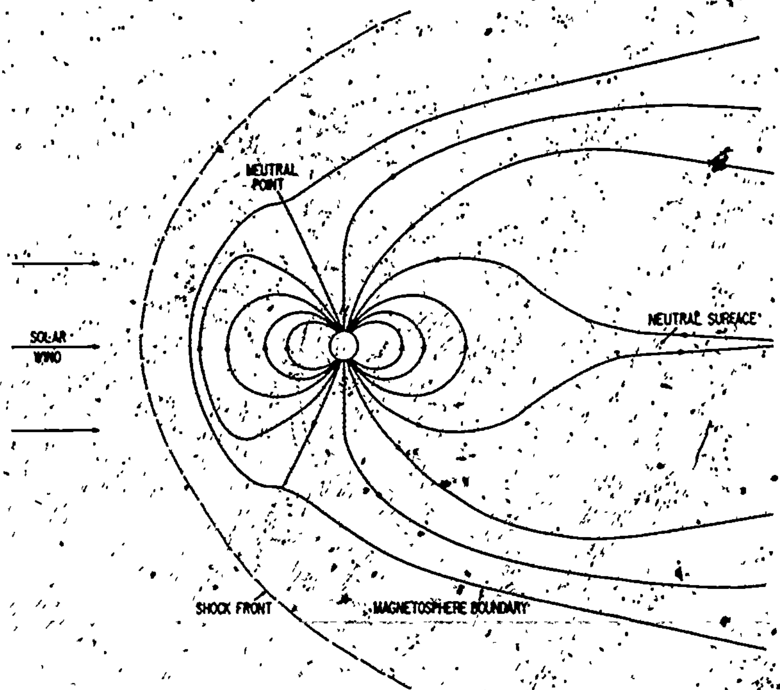

Figure 57. Magnetosphere surrounding the earth. The magnetosphere protects the earth against harmful radiations from space.

radiation belts, (3) galactic cosmic rays (those coming from beyond the solar system), and (4) the solar wind. Of these, the first three are the potentially dangerous radiations in space. The solar wind, although found in abundance throughout space, does not present a danger to man. The protons and electrons in the solar wind are too weak to penetrate the wall of the spacecraft or even the space suits of the astronauts.

The **solar-flare particles,** or the solar cosmic rays emitted during flares on the sun, are believed to be the most dangerous kind of space radiation. A solar flare is a spectacular disturbance on the sun observed in the telescope as a sudden large increase in light (Fig. 58). A flare may last from several minutes to a few hours. Perhaps as many as a dozen dangerous flares occur in the sun each year, but more than this take place during the time of peak activity in the 11-year sunspot cycle. A large solar flare may increase cosmic-ray intensity in the vicinity of the earth by as much as a hundred times and maintain high levels of radiation for several days. The best means of avoiding the danger from solar flares are to schedule spaceflights at a time when such

Figure 58. Solar flares. These flares are erupting as far as 500,000 miles into space. Solar flares increase the intensity of cosmic rays in space.

flares are least likely to occur and to set up a warning system. When the Apollo flights to the moon were being made, space officials set up a system of warning that used telemetered data from satellites, supplemented by studies of the sun made in observatories on the earth.

The second greatest danger from radiation is that from the **charged particles trapped in the Van Allen radiation belts** surrounding the earth (Fig. 59). In the regions where the radiation in these belts is the highest, it is intense enough to kill an unprotected man within a few days. To avoid exposure to radiation from the Van Allen belts, all spaceflights in earth orbit are planned so that they avoid the regions where the belts bend down toward the atmosphere, and the flights are kept below an altitude of about 500 miles. When the Apollo astronauts had to pass through these belts on their way to the moon, they went through them rapidly, and exposure was kept to a minimum.

The **galactic cosmic rays**, or the cosmic rays that come from outer space, are a potential hazard because of their very high energy levels. Fortunately, however, these radiations are not abundant, and the particles in the radiation are usually made up of protons and helium nuclei, which do not present a danger in small quantities. Weight limitations prevent using thick metal shields on spacecraft as protection against cosmic rays. Even if such shields were practicable, it would not be advisable to use them. If a few high-energy primary cosmic rays managed to penetrate the shields, they might create a shower of secondary cosmic rays within the spacecraft that would cause more harm than the original cosmic rays.

Even though metal shields are not used on spacecraft, the astronauts are provided with some **shielding against space radiation.** The mass of the spacecraft structure and of the electronic equipment and water supplies stored on board gives some protection. Whenever possible, the equipment is positioned in the spacecraft so as to give the greatest amount of shielding.

To give future astronauts better protection against radiation in space when they are exposed to it for longer periods, doctors will need to obtain more precise information about the way space radiation affects the human body. As the result of data obtained from experiments with living matter carried by the American Biosatellite 2, space scientists believe that man is more susceptible to radiation in space than on the earth. The effects of

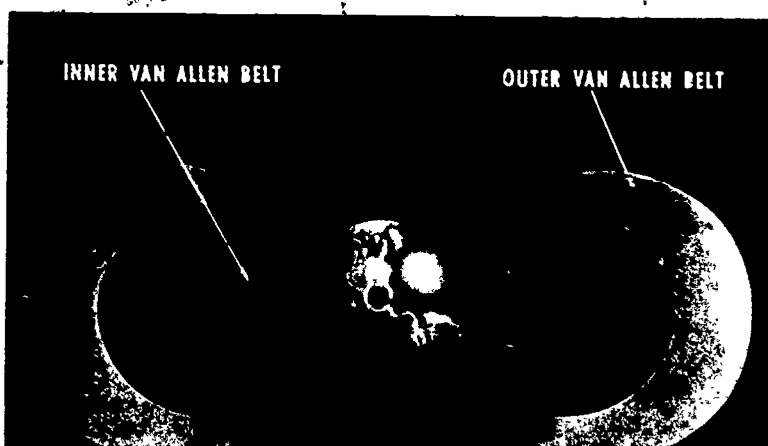

Figure 59. Cross section of Van Allen radiation belts. The areas in which radiation from these belts is most intense represent a hazard to man.

space radiation on the human body are judged in terms of the effects produced by manmade radiation, such as that emitted by medical X-ray machines or by a nuclear explosion.

Manmade ionizing radiations harm the body by causing the breakdown of the cells. The cells of certain systems of the body, such as those of the circulatory system, the digestive system, and the central nervous system, are more susceptible to damage from radiation than other cells. When a certain number of cells in the body break down or a vital organ is impaired, then sickness and sometimes death result. The damage caused by ionizing radiation depends upon the size of the dosage, the total area exposed, the kinds of cells exposed, and other factors.

The unit most widely used for measuring the biological effects of radiation is the **rad** (from radiation absorbed dosage). A person given a chest X ray is likely to absorb about 0.25 rad. An astronaut exposed to a moderate to large solar flare while inside a shielded spacecraft would not be likely to receive more than 100 rads. An astronaut going quickly through the Van Allen radiation belts in a shielded spacecraft might receive about 5 rads on each passage.

To get some idea of the possible damage from exposure to radiation in terms of rads, you might consider what happens when the entire body is exposed to radiation in its most acute form on the earth (Fig. 60). Under these circumstances if an entire population were exposed, a dose of about 225 rads might be expected to cause almost 60 percent of the population to become sick within about three hours. A dose of about 490 rads would cause 80 percent of the population to die within 30 days. The effects of radiation on the human body are cumulative, that is, they build up over a lifetime. While the effects of a severe dose of radiation would produce drastic results, exposure to small doses might pass unnoticed but add up until they finally became harmful. For this reason it would seem advisable to limit the number of spaceflights that astronauts make into regions where they are exposed to harmful radiation.

Fortunately, the data about the effects of radiation on living matter that we have at present has been obtained from chance exposure of persons to manmade radiation or from experimental animals. So far as is known, there have been no human victims of natural radiation. Although American astronauts are known to have been exposed to small amounts of radiation, both in their spacecraft and on the moon, they have suffered no harmful effects. Also, military pilots have been flying aircraft at very high altitudes for a number of years, but they have shown no cumulative effects from radiation.

The potential danger from ionizing radiation in space does exist, however, and it must be taken into account in planning future spaceflights. More accurate means of predicting solar flares are likely to be developed, and additional means of shielding the spacecraft are under study. Soviet cosmonauts have used chemicals and drugs to give them protection against radiation, but American doctors do not favor using drugs, as these may cause side effects.

Meteoroids

A second hazard to man in space is that from the small pieces of matter known as **meteoroids.** The very smallest particles, which are about the size of specks of dust, are called **micrometeoroids.** Even though all meteorite material is quite small, the particles can generate considerable energy because they travel at speeds varying from 30,000 to 160,000 mph. At these speeds, an impact of one of the larger meteoroids with a spacecraft would be disastrous. The meteoroid would break the seal of the spacecraft and cause rapid decompression. Its effects on an astronaut in extravehicular activity (EVA) would be even swifter and more catastrophic. The very small meteoroids, or the micrometeoroids,

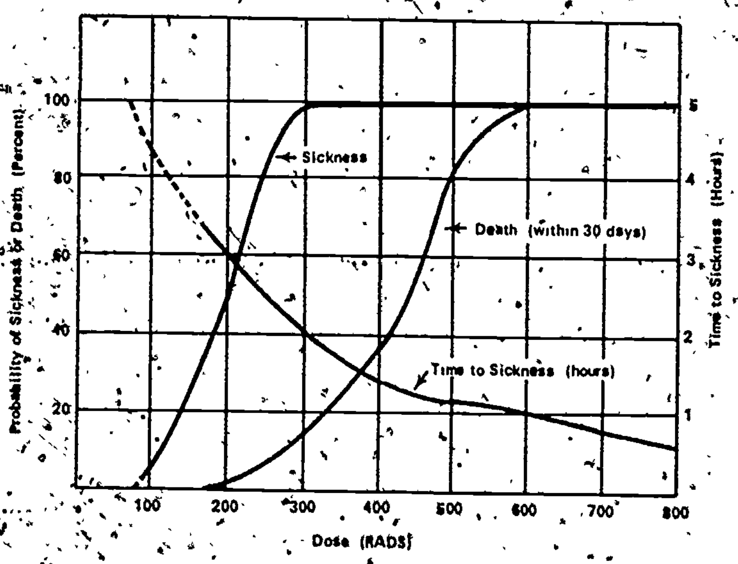

Figure 60. Estimate of the effects of different doses of acute whole-body radiation on man (Air University Space Handbook). Individuals vary greatly in their tolerance of radiation.

would not puncture the seal of a spacecraft or even a space suit, but they do cause erosion of surface materials.

To protect man against the possible impact of meteoroids, engineers use a **meteorite bumper.** On the American spacecraft the bumper is the outer, or second, wall of the module carrying the astronauts (Fig. 61). On EVA suits, the bumper is an extra layer of material. If a meteoroid were to strike against a bumper, it would spend its energy in puncturing the bumper, and the seal of the space cabin or space suit would remain intact.

Before manned spaceflights began, scientists believed there was a great potential danger to astronauts from strikes by meteoroids. Because of studies made with the special Pegasus satellites and

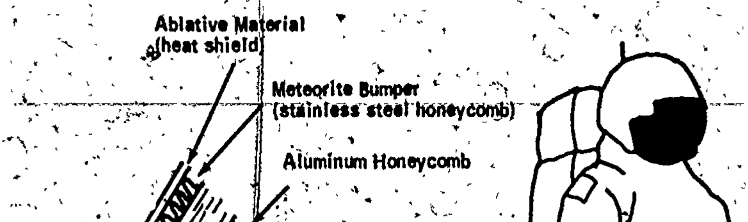

Figure 61. Meteorite bumpers. The outer wall of the Apollo command module acts as a meteorite bumper. The many-layered white coveralls of the Apollo moon suit also acted as a meteorite bumper.

other spacecraft, scientists now believe that there is little likelihood that a spacecraft would be hit by a meteoroid large enough to cause decompression. The possibility does exist, however, and efforts will be made to construct better bumpers or possibly self-sealing walls for spacecraft.

Weightlessness

The third stress new to spaceflight, the condition of weightlessness (zero gravity), is brought about because centrifugal force balances the force of gravity and cancels it out during orbital flight. This means that just as soon as the spacecraft goes into orbit, it becomes weightless, as well as the passengers and everything else in it. Fluids break up into droplets and float about in the spacecraft if not kept in closed containers. The astronauts float as they move about, whether in the spacecraft or in extravehicular activity (EVA). Weightlessness continues as long as the spacecraft is in orbit and no thrust is added to the vehicle. When propulsive power is applied to the spacecraft to maneuver or to bring the spacecraft out of orbit, gravity force is felt once again.

Before man went into orbital flight, there were fears about what would happen to the human body once it became weightless. Some scientists believed that man while weightless would have a continual feeling of falling that would in time become unbearable. Others believed that the vital organs would stop functioning or would not function in a normal way, causing all kinds of maladies.

The early fears about the weightless condition have been laid to rest, but these fears were not groundless. All the organs and systems of the body have become adjusted to functioning in a condition of earth gravity (1 G). When the body is suddenly subjected to increased G-forces at launch and then brought to a condition of weightlessness in orbit, the central nervous system must bring about adjustments within the body cells and tissues to maintain them in a stable condition in order to sustain life. Scientists have observed that certain changes seem to take place within the body as it adjusts to the weightless condition in orbit, such as changes in the circulatory system and in the muscles. Then when the spacecraft drops out of orbit and the astronauts come back to the earth, the body adjusts to earth gravity again.

Extended experiments on the real weightless condition cannot be duplicated on the earth. You may feel weightless when you drop quickly in an elevator or make a steep dive on a roller coaster, but your body is being subjected to gravity force all the time. There is no counter force to cancel out the gravity force, as there is during orbital flight. The only way that true weightlessness can be duplicated is to fly a **weightless trajectory,** or a parabolic arc, in a high-performance aircraft. This is done by making a power dive and then a steep climb and a nose-over (Fig. 62). At the top of the trajectory, a condition of weightlessness (Fig. 63) is attained for a matter of 30 to 40 seconds. Pilots accidentally discovered the effects of this weightless trajectory during World War II. Later, flight surgeons at the Air Force School of Aviation Medicine reproduced the flight trajectory to study the condition of weightlessness in anticipation of spaceflight. Persons who flew the weightless trajectories reported varying reactions. Some found the condition pleasant and relaxing, but others experienced nausea and disorientation during weightlessness.

Just before the first spaceflights were made, scientists used tests with subjects confined in bed to approximate the weightless condition. Later, after the astronauts had some difficulty in performing space work during EVA, they began to experiment with underwater workouts with scuba diving equipment to simulate conditions in orbit. They found that the condition of the body in neutral buoyancy underwater is similar to that in space. Confinement in bed and underwater practice still leave the body subjected to the earth gravity force. Weightlessness can only be approximated on the ground.

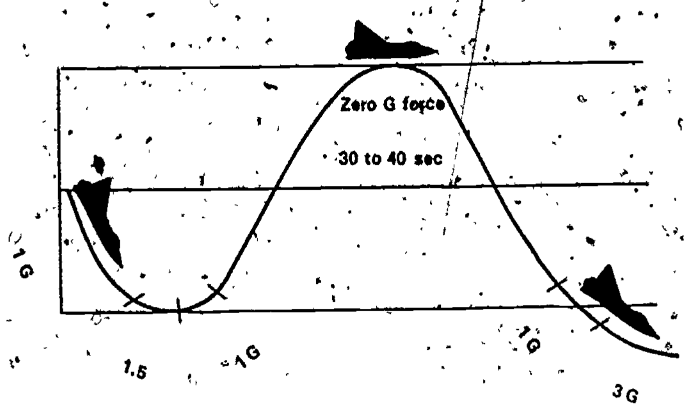

Figure 62. Weightless flight trajectory. After making a power dive, the aircraft noses upward and then coasts through a weightless arc.

Figure 63. Astronaut experiencing weightlessness. Astronaut David R. Scott is training with a maneuvering unit during a weightless flight trajectory.

American astronauts have successfully overcome the effects of being weightless in orbit for periods up to two weeks,[1] and they have readjusted to normal earth gravity again after their flights. The question still remains as to what will happen to the body during longer periods of weightlessness.

The Soviet cosmonauts have reported some experiences with nausea during weightlessness, and they have experienced some difficulty in readjusting to earth gravity after longer flights. After the Soviet cosmonauts returned from the new world record flight of 18 days in the Soyuz 9, in June 1970, they had to be helped from their spacecraft. The weightless condition appeared to have affected their coordination, and it took about five days for their bodies to return to normal after the flight.

[1]After this book went to press, the Skylab 1 astronauts made a new American record with their successful 28 day flight in orbit. Time in orbit should be increased even more on later visits to the Skylab.

The experiences that some pilots have had during weightlessness might help to explain the death of the monkey Bonny. In June 1969 Bonny was placed in orbit for a scheduled 30-day flight in the American Biosatellite 3 in order to collect data about weightlessness. After about 9 days in orbit, Bonny became sluggish, and then, after being brought back to earth and safely recovered, died about 12 hours later. An autopsy showed that death was caused by heart failure, which was probably brought on by a combination of weightlessness, immobility, and cold.

The principal means proposed for countering weightlessness is to rotate the spacecraft and in this way create **artificial gravity.** Engineers have suggested that modules of a space station that are to be inhabited could be rotated. At present there are no plans for rotating US spacecraft. The Skylab will be orbited without rotation, permitting scientists to collect data on the reactions of the human body to longer periods of weightlessness.

Perhaps we have tended to overemphasize the unknown in spaceflight and have overlooked the importance of known stresses. Consequently, space scientists continue to study the effects on man of such known stresses as increased G-forces, heating, noise and vibration, and lack of atmosphere.

Increased G-Forces

As man went into spaceflight, speeds increased from supersonic to cosmic speeds. All vehicles that orbit finally reach a speed of at least 17,500 mph. The Apollo spacecraft, launched on a free-return trajectory to the moon, reached a speed of more than 24,000 mph as it left the earth and as it returned to the earth. As a result of rapid acceleration and deceleration, astronauts have been subjected to a new order of G-forces.

When the rocket booster accelerates at launch, G-forces reach a level varying from 3 to 8 G. At reentry the astronaut is again subjected to increased G-forces when the spacecraft impacts with the atmosphere and then by the opening of the parachutes. A profile of the G-forces felt by astronauts is shown in Figure 64.

When the Mercury spacecraft reentered the atmosphere, it dropped like a ballistic body. The Mercury astronauts reported some shock as they impacted the atmosphere and as the large parachute opened. Considerable lifting ability was built into the Gemini and Apollo reentry modules. These modules usually reentered at greater speed than the Mercury spacecraft, but because of their lifting abilities, they came down more gradually. This kept the G-forces at reentry within tolerable limits.

Even though the increased G-forces experienced in spaceflight have been considerably lower than at first estimated, they are far greater than those experienced in aircraft maneuvers. In spaceflight the greatly increased G-forces at launch and reentry can be tolerated by the astronaut because he is lying down. In this position the G-forces act across the body, not from head to foot as with the seated pilot (Fig. 65). G-forces acting across the body are known as **transverse G-forces.** For years engineers have tried to find ways for placing the pilot of an aircraft in a reclining position so that he could take the G-forces across his body, but it is impossible for a pilot to control an aircraft while lying down.

On the Mercury spacecraft a form-fitting couch was used for the astronaut, but this was found to be too confining. On the Gemini and Apollo spacecraft the astronauts use a seat that allows them to recline with head and legs slightly raised. In this reclining position the length of the critical blood column, or the distance that the heart must pump blood to reach the brain and eyes, is greatly reduced, as shown in Figure 65. Thus the strain on the

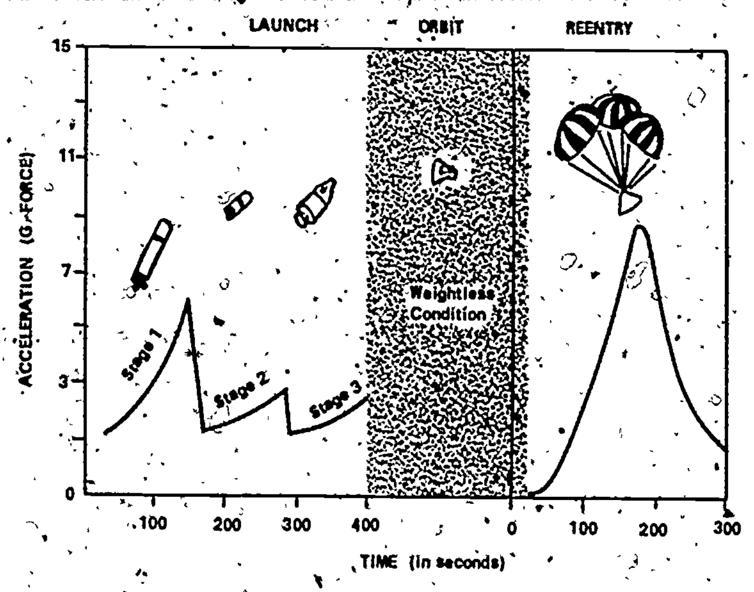

Figure 64. Typical G-forces during different periods in flight of spacecraft launched by a three-stage booster. At reentry the G-forces increase as the reentry module impacts the atmosphere and again as the parachutes open.

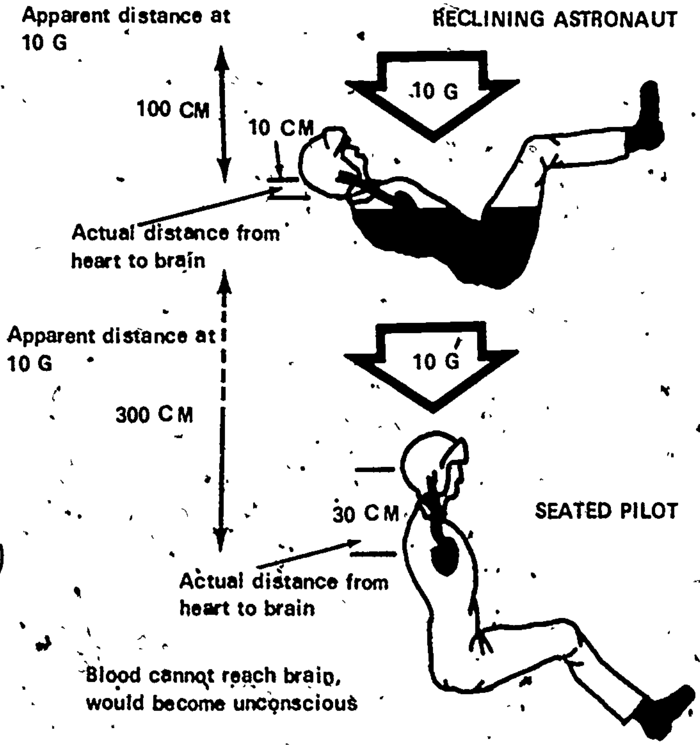

Figure 65. Direction of G forces on body of reclining astronaut and seated pilot. For the astronaut, the G-forces are transverse. They act across the body from chest to back. For the seated pilot, they are vertical (positive). They act from head to feet. For the astronaut, the vertical distance between the heart and the brain and eyes is about 10 cm. For the seated pilot, it is about 30 cm. A force of 10 G is equal to increasing the vertical distance 10 times.

heart is likewise reduced, and the astronaut is able to take forces as high as 20 G for a brief period.

The astronaut's arms and legs become immobile when subjected to high G-forces, however. The arms cannot be effectively controlled if the G-forces reach more than about 4 G. The hands and fingers can tolerate forces of 7 to 9 G, but they could not operate conventional aircraft controls under such heavy loads. For this reason side-stick controls are used on a spacecraft for controlling pitch, roll, and yaw, and on the spacecraft the position of these controls has been changed from that used in an aircraft.

Heating

When the reentry module, or the module of the spacecraft in which the astronauts travel, is ready to be launched, it rests at the top of the stack on the launch pad, with the small end uppermost. As the module is launched, the small end impacts the atmosphere (Fig. 66), offering the least amount of resistance and therefore causing the least amount of aerodynamic heating.

At reentry the large blunt end of the reentry module impacts the atmosphere, thus slowing down the spacecraft but causing intense frictional heating as it does so. The heating is so great that flames envelop the module (Fig. 66). When the reentry module of the Apollo spacecraft (the command module) impacted

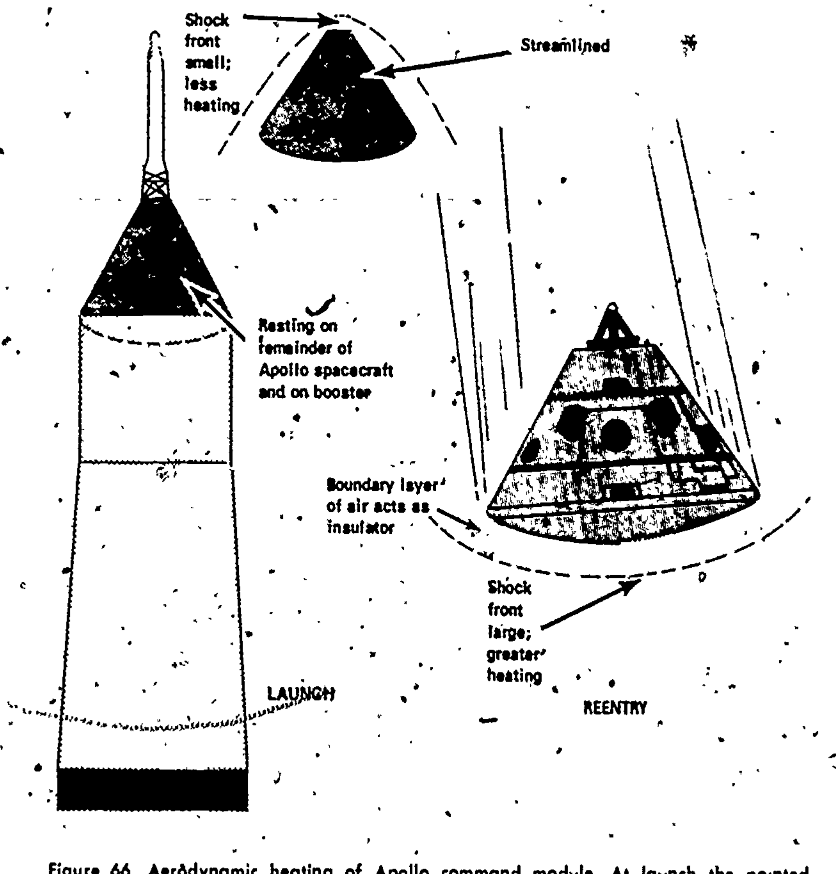

Figure 66. Aerodynamic heating of Apollo command module. At launch the pointed end of the module impacts the atmosphere, and heating is slight. At reentry the large blunt end impacts, and heating is intense. Flames envelop the module.

the atmosphere at speeds of more than 24,000 mph, some surfaces on the module reached temperatures as high as 5,000 degrees F. The protective heat shield on the Apollo command module covers not only the blunt end, as on the Mercury spacecraft, but the sides of the module as well.

The fiery reentry is another feature of spaceflight that makes it different from aircraft flight, and the need to protect the spacecraft at reentry complicates space rescue. A pilot can eject from an aircraft at the very limit of the flight atmosphere and be saved, as demonstrated by the parachute jumps of Captain Kittinger, but at present no astronaut could escape from a disabled spacecraft and reenter the atmosphere. He would be burned up like a meteor.

Besides frictional heating on the outside of the spacecraft, other heat builds up on the inside. The bodies of the astronauts give off considerable heat, a large amount of heat is generated by the electronics equipment, and heat rays are transmitted directly from the sun. The total load of heat within the spacecraft is usually quite large, and heat must generally be dissipated. There are times, however, when additional heat may be needed, as when the spacecraft is shielded from the sun's rays. To regulate the temperature within the spacecraft, a central environmental control system is used, which is described later.

Noise and Vibration

The greatest stresses from noise and vibration in spaceflight are experienced when the rocket booster launches the spacecraft into orbit. When the thrusters on the spacecraft itself are fired during flight, the noise and vibration they generate represent only distraction or irritation. The rockets that fire at launch, however, cause real physiological stresses.

At launch the successive firings of the stages of the large rocket boosters produce noise levels of 145 to 175 decibels. These are well above the upper limits of man's tolerance to noise, or the levels of 140 to 150 decibels. The rocket engines of the Saturn V, the largest space booster by far, produce the loudest noise. Fortunately, the Apollo astronauts were shielded against dangerous noise levels by being placed at a considerable distance from the rocket engines. At liftoff their module rested near the top of the 364-foot stack, just under the escape tower. They were further protected from the roar of the Saturn engines by the double walls of the command module and by their thick helmets. The astronauts in the Mercury and Gemini spacecraft were much closer to the rocket engines as they fired at launch, but these engines generated far less noise than the Saturn engines.

With the earlier space boosters, the Atlas and the Titan II, which were used to boost the Mercury and the Gemini spacecraft, respectively, vibration rather than noise was the principal problem. The Atlas booster was developed from a first-generation ballistic missile, which generated considerable vibration as it fired. To **manrate** the Atlas missile, or make it safe for launching a manned spacecraft, the vibrations had to be dampened out or eliminated. This was necessary because many of the vibrations in the booster were in the low range of 1 to 10 cycles per second. Vibrations in this range would have set up dangerous vibrations in the spacecraft, causing certain vital organs in the astronaut's body, such as the lungs and the abdominal systems, to vibrate along with them. This would have caused tearing of the tissues holding the organs in place and could have produced fatal results. Since the Saturn boosters were developed for launching a manned spacecraft, dangerous vibrations could be eliminated in the design or early tests.

Noise and vibration, intense frictional heating, and greatly increased G-forces are stresses felt during the powered phase of spaceflight or at reentry. All the time a spaceflight is in progress the astronauts must protect themselves against low barometric pressure.

Lack of Atmospheric Pressure

Since a spacecraft must be designed to operate in the near vacuum of space, it must be able to take the total pressure of the cabin atmosphere across its walls as the pressure outside becomes zero. Up to the time of the Skylab launch, a pure oxygen cabin atmosphere pressurized at about 5 psi had been used in US spacecraft. Such an atmosphere provided enough oxygen pressure to protect the astronauts against hypoxia and to give adequate counterpressure against the body. Soviet engineers have duplicated the natural atmospheric gases and maintained a pressure of about 14.7 psi in their space cabins. Such an atmosphere requires a much heavier structure to contain it and withstand the tremendous pressure across the cabin walls. From the beginning the Soviets have built much heavier spacecraft than we have. They were able to launch such spacecraft because their space boosters were much more powerful than ours.

Regardless of the atmosphere used, the danger of decompression is an ever present hazard. It is unlikely that a large meteoroid would puncture the wall of a spacecraft and cause decompression, but there is real danger of a mechanical failure in some element of the pressurization system or in the spacecraft structure. For pilots of high-flying aircraft the time of useful consciousness, or the time allowed for taking emergency measures when deprived of oxygen, becomes a matter of seconds. For the astronaut in space, this time approaches zero.

In spite of the potential hazards of decompression in space, there had been no instances of such decompression up to June 1971. Then three Soviet cosmonauts in the Soyuz 11, after making what would have been a new record stay of 24 days in space, died as they were reentering the atmosphere. The module in which they were traveling developed a leak in a hatch as it separated from another module. An autopsy revealed that the victims probably died of an air embolism, or the injection of air into the bloodstream from their ruptured lungs. Their bodies showed the most severe signs of decompression. Much of the blood had evaporated, or boiled away.

After US space officials received a report on the accident, they took added precautions to insure that the astronauts wore space suits at hazardous times during the flight. Additional safety measures for American astronauts are the warning signals built into the environmental control system in their spacecraft.

ENVIRONMENTAL CONTROL SYSTEM

In the spacecraft, just as in high-flying aircraft, a pressure suit (space suit) is used as a backup for the space cabin. During the greater part of the flight, the astronauts remove their space suits and enjoy the pressurized environment of the space cabin, or what is called the **shirt-sleeve environment.** During the most hazardous parts of the flight, the astronauts put on their space suits to be in readiness for an emergency. They also wear their space suits when they are depressurizing the spacecraft in preparation for EVA or are actually engaged in EVA. Whether the astronauts are enjoying the shirt-sleeve environment or are wearing their space suits, they are receiving oxygen support from a central system.

In a spacecraft, unlike in an aircraft, oxygen support is not given separately. Instead it is part of a complex life-support system called the **environmental control system.** Such an integrated system is needed for controlling the environment during spaceflight because the astronauts must adjust to living and working in the near vacuum of space for extended periods. They cannot return to the earth to take on more oxygen or life-support supplies or drop back to the ground quickly in case of an emergency. In a spacecraft the space suit and the space cabin are tied into the larger environmental control system.

Space Cabin

The environmental control system of the spacecraft is located within the space cabin, or the module in which the astronauts ride during the flight. The system channels a supply of pressurized oxygen to the space cabin, and it has warning signals to let the astronauts know if a leak should develop in the system. This would be in addition to the small amounts of oxygen that naturally seep through the walls of the spacecraft even though they are tightly sealed. Since gas molecules are highly active, they continually try to move from the pressurized area of the spacecraft to the region of near zero pressure in space. Also, when the astronauts left their module for EVA, they had to depressurize the spacecraft by allowing all the oxygen to "bleed out," and they had to renew the oxygen supply when they returned. All the time the astronauts were within the spacecraft, however, they depended upon the environmental control system for their oxygen supply.

Besides providing the supply of oxygen for the space cabin, the environmental control system removes carbon dioxide, solid particles and other contaminants, and water vapor from the cabin atmosphere and provides a means for cooling the cabin. The diagram in Figure 67 shows how the environmental control system operates in the command module of the Apollo spacecraft. The oxygen enters the system from the service module, where the oxygen supply is stored. The surge tank in the command module carries reserve oxygen that is used at reentry after the command module has separated from the service module. A similar system was used on the Gemini spacecraft. On the Mercury spacecraft the oxygen supplies and the environmental control system were both contained in the single module.

Since the astronauts are closely confined in the space cabin, it is vital that all contaminants and noxious gases and vapors be removed from the atmosphere and that it be constantly purified. NASA has developed a small, reliable system for detecting harmful gases in the space cabin, and a simple but reliable means has been used for purifying the breathing atmosphere.

Carbon dioxide is removed from the cabin atmosphere by trapping it in the chemical **lithium hydroxide** contained in metal canisters (Fig. 68). These canisters were also used in the lunar module. When the astronauts on the Apollo 13 were making use of the lunar module as their "lifeboat," they noticed that the canister in the module was no longer effective and that carbon dioxide was building up to dangerous levels. With the help of ground control, the astronauts rigged up a makeshift lithium hydroxide canister to purify the atmosphere. The regular canister

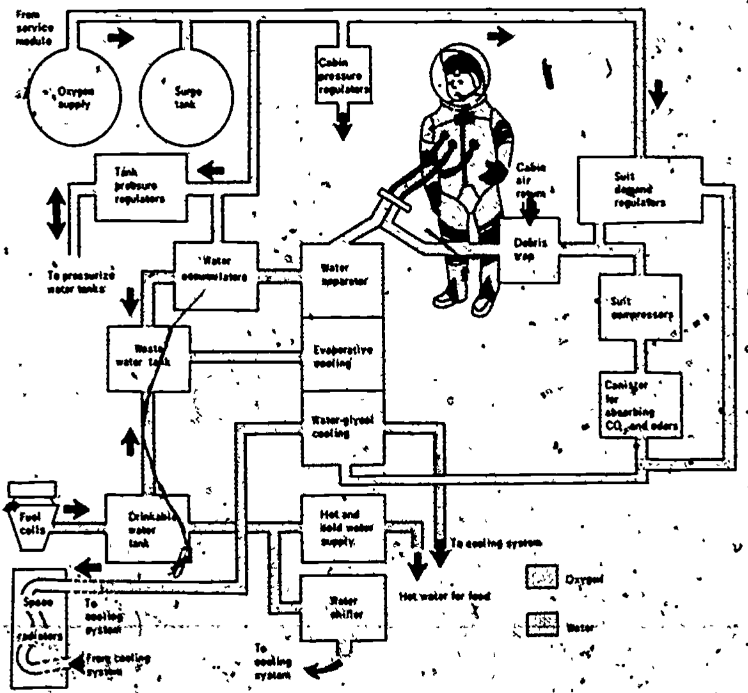

Figure 67. Environmental control system of the Apollo command module. This diagram shows how water and oxygen are channeled in the life-support system. The Apollo spacecraft makes use of a semiclosed life-support system.

also contains charcoal filters, which absorb odors and noxious gases; and glass-cloth filters, which trap small solid particles and keep the lithium hydroxide from getting into the atmosphere. Large solid particles are caught by another device, a debris trap made of fine-mesh wires.

The water vapor in the cabin atmosphere, which accumulates in large quantities from the astronauts' breathing and perspiration, is removed from the atmosphere and recovered. The recovered water, mixed with a coolant (glycol) can be circulated through the space cabin. The circulating fluid picks up heat from the principal heat sources and then flows to the radiator located on the outside of the spacecraft. On the flights to the moon the spacecraft was rotated slowly at intervals (what the astronauts called the "barbecue mode") to allow even exposure to space and to permit more heat to escape from the radiator. In space it is not a simple matter to lose the heat that builds up within the sealed cabin. On earth there are three means of transferring heat: radiation, convection, and conduction. In space there is only one method; **radiation.**

Just as it is difficult to reproduce cooling methods in space, it is also difficult to make up an artificial atmosphere that is as satisfactory as the real earth atmosphere. The ideal atmosphere for a space cabin would be a mixed gas pressurized at 14.7 psi, just as the earth's atmosphere is. Using such an atmosphere for US spacecraft in the beginning presented too many problems. On the first three series of US spaceflights (Mercury, Gemini, and Apollo), a pure oxygen atmosphere was used at much less than atmospheric pressure. Pure oxygen presents a fire hazard, as was shown by the tragic fire on the launch pad during a test of the Apollo command module in January 1967. This fire took the lives of Astronauts Grissom, White, and Chaffee. After the fire,

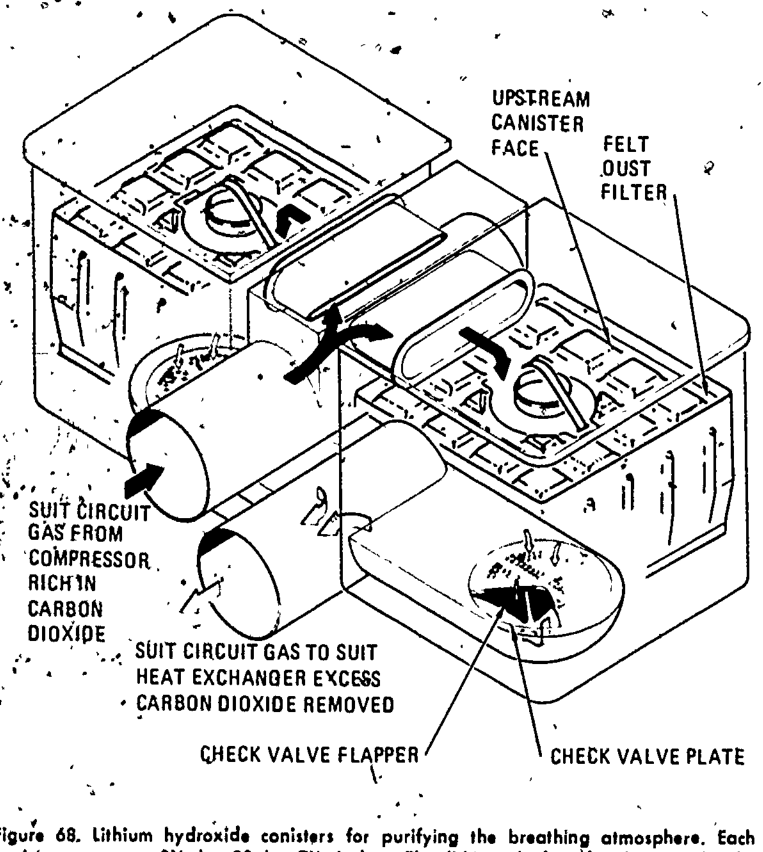

Figure 68. Lithium hydroxide canisters for purifying the breathing atmosphere. Each canister measures 3½ by 20 by 7½ inches. The lithium hydroxide elements in the canisters are changed alternately, one every 12 hours.

the module and the space suits were modified to make them fire-resistant, but the danger of breathing pure oxygen for prolonged periods still remained.

Pure oxygen can be breathed at reduced pressures at altitude for periods up to 15 days without causing harm. If the astronauts were to breathe pure oxygen for periods beyond this time, they might begin to show some of the effects of **oxygen poisoning,** the cause of which is not yet understood. In addition to causing poisoning, the breathing of pure oxygen for prolonged periods causes other changes in the body, such as the drying of the mucous membranes. Doctors have given 30 days as the limit for astronauts to breathe pure oxygen in the spacecraft. Since the second and third visits of the astronauts to the Skylab are scheduled to last longer, a **mixed-gas atmosphere** is to be used for the Skylab. Nitrogen will be used to dilute the oxygen. The mixed gas will be used in both the space cabin and the astronauts' space suits.

Space Suits

The space suits worn by the astronauts developed from the full-pressure suit of the combat pilot. About two years after the first full-pressure suit was ready for use, spaceflight began. The Mercury space suits grew out of the Navy full-pressure suit, and the Gemini and Apollo suits developed from the Air Force full-pressure suit and from the research findings made by the Air Force. The security, comfort, and mobility needed for use in space for extended periods led to the design of a true **space suit** (Fig. 69). As the Mercury, Gemini, and Apollo flights progressed, the space suits designed for these flights were improved. Developing space suits for the astronauts has required the same kind of advances in engineering and biomedical knowledge as were needed to develop the spacecraft itself.

In the course of spaceflight the astronauts have acquired a wardrobe of space clothing. There is the space suit that is worn inside the vehicle and the space suit that is worn outside, or the **EVA suit.** In addition, the astronaut has a **space undergarment,** or space underwear. Each garment is fitted individually and tagged with the astronaut's name.

After the Gemini flights were underway, a new lightweight, easily removed space suit was developed (Fig. 70). Beginning with the Gemini-7 flight, the astronauts have taken off their space suit inside the spacecraft and have spent a large part of the time in their space underwear, enjoying the shirt-sleeve environment.

When the Gemini-7 astronauts returned to earth, they were in excellent physical condition. Dr. Charles Berry, their flight surgeon, stated that their improved condition might in part be explained by the fact that they were more comfortable and sweated less than the astronauts who wore their space suits throughout the trip.

There are two kinds of space undergarments: the garment designed for air cooling, which is worn inside the spacecraft, and the garment with coils for water-cooling, which is used outside the spacecraft. The water-cooling system must be used with the backpack and the small portable radiator. Both kinds of space underwear have attachments for a communication belt, equipment for collecting urine, and the biomedical instrumentation belt. The undergarment acts as the bottom layer of the space suit.

In developing space suits, scientists and engineers faced similar problems as in perfecting pressure suits for combat pilots, but their problems were much more difficult to solve. The space suits are subjected to an even larger amount of ballooning when the pressurized bladder is used in the vacuum of space. With the space suit, as with the pilot's pressure suit, another layer of material is used to hold the pressurized bladder in place. The principle of layering, used in Wiley Post's first successful pressure suit,

Figure 69. Astronaut John Glenn in Mercury space suit. Glenn was suited up for the first US orbital spaceflight. Note the pockets on the suit for holding useful items.

has been applied to the space suit. In the space suit there are more than two layers of material, and each layer serves a different purpose. This is shown in the diagram of the Gemini EVA suit (Fig. 71).

One of the problems that plagued the astronauts on the first longer EVAs on the Gemini flights was inadequate ventilation of their EVA suits. Space work required the expenditure of more energy than first estimated, and the astronauts perspired freely

Figure 70. Lightweight space suit worn on 14 day Gemini flight. Astronauts Frank Borman and James Lovell are shown as they went to the elevator in preparation for launch.

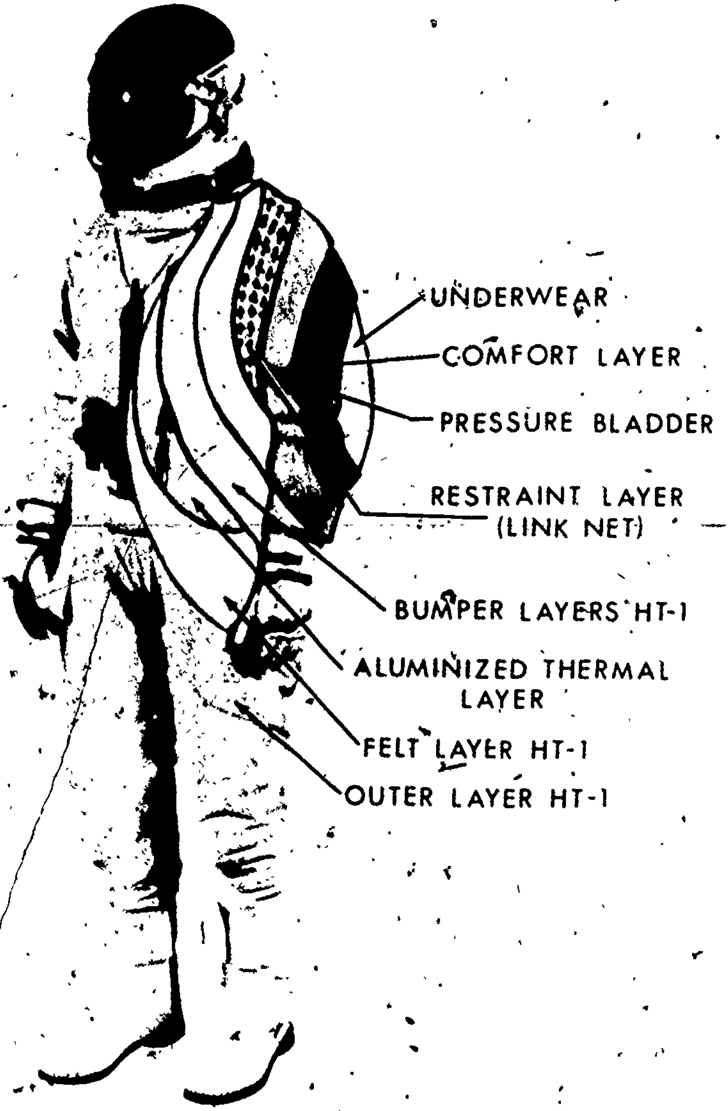

Figure 71. Cutaway drawing showing layers of Gemini EVA space suit.

while doing space work. Since the moisture from their perspiration was not removed from their EVA suits quickly enough, their helmets fogged over. During EVA on the Gemini-9 flight, Astronaut Eugene Cernan had to stop his space work and return to the spacecraft because he was blinded. His helmet fogged over and then frosted, since the spacecraft was on the dark side of the earth. By the time the Gemini flights were coming to an end, the EVA suit had been perfected, and fogging of the helmet was no longer a problem.

The Apollo **moon suit** (Fig. 72) was the most advanced kind of space suit developed up to this time. It was actually a miniature spacecraft for temporary use on the moon. When dressed in his moon suit, the astronaut carried his oxygen supply in the backpack, called the **Portable Life-Support System (PLSS).** This made the astronaut independent of the lunar module during EVA. The Gemini astronauts were connected with the spacecraft during EVA, and they received oxygen through an **umbilical** contained in the tether, together with the communication line. The moon suit had its own communications equipment and oxygen supply, together with a supply of drinking water and orange juice, biomedical instrumentation, and provisions for urine and feces collection. An overgarment worn with the moon suit gave protection against radiation and impact by meteoroids on the airless surface of the moon. The undergarment worn with the moon suit contained the coils that allowed water-cooling of the suit to protect the astronaut against the temperatures of 250 degrees F. or even higher that he encountered on the sunlit surface of the moon. The special gold-coated visor in the helmet of the moon suit protected the astronaut against glare and harmful radiation from the sun. A system of bellows in the arms and legs of the suit allowed greater freedom of movement than the elasticized link net, or "fish net," used in the combat pilot's suit and in the Gemini EVA suit.

The moon suit was resupplied for the next EVA when the astronauts returned to the lunar module. At this time they picked up new oxygen tanks, water reservoirs, batteries for electric power, and lithium hydroxide elements for the canisters.

When the oxygen supply in the environmental control system is channeled to the suit, either in the spacecraft or during EVA, the pressure of the oxygen is stepped down from the cabin pressure of about 5 psi to a pressure of about 3.5 psi. Lowering the pressure prevents the space suit from ballooning too much and thus allows the astronaut greater freedom of movement. The lower pressure still provides adequate counterpressure against the body.

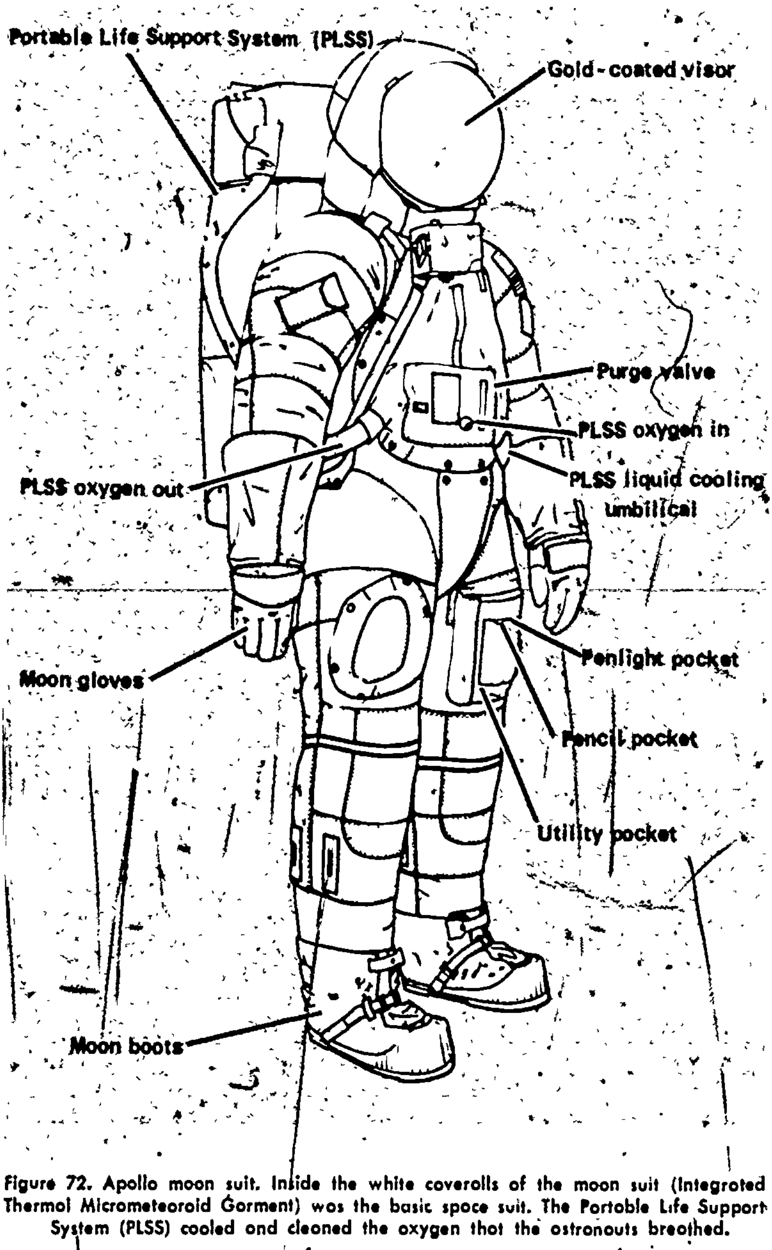

Figure 72. Apollo moon suit. Inside the white coveralls of the moon suit (Integrated Thermal Micrometeoroid Garment) was the basic space suit. The Portable Life Support System (PLSS) cooled and cleaned the oxygen that the astronauts breathed.

LIVING IN SPACE

The environmental control system, which regulates the oxygen supply, forms part of the larger life-support plan. On the long space voyages envisioned for the future, all the life-support supplies—the food and water, as well as the oxygen—is to form part of a single system and is to be recycled or reclaimed for use again, just as is done in nature on the earth. Such a system, patterned after the earth's ecology, or the relationship between living things and their environment on the earth, is known as a closed ecological system, or simply a closed system. The other extreme is the **open life-support system** used in aircraft. In the open system all supplies needed for life support—oxygen, water, and food—are put on board for each flight and replenished for the next. Everything is brought in from the outside; nothing is recycled.

From the beginning of spaceflight both the Americans and the Soviets have used a system that is somewhere between the open and closed system, or what is called a **semiclosed life-support system.** They have recycled some of their life-support supplies.

Life-Support Supplies

To understand why a semiclosed life-support system is used in spaceflight, it is only necessary to consider the large daily requirement that each astronaut has for essential oxygen, water, and food. In a completely open system, each astronaut would need a minimum of about 28.7 pounds of **life-support supplies** each day, and this would be converted into 28.7 pounds of waste, some of which would have to be stored on board. The amount of input of each item of life support and the output of this item is estimated as follows:

Input	*lb. per day*	**Output**		*lb. per day*
Oxygen	22.7	Oxygen waste		20.7
Water	4.7	Water waste		5.2
		Water vapor	2.2	
		Urine	3.0	
Food	1.3	Food exchange		2.8
		Carbon dioxide	2.2	
		Solid waste	0.6	
Total supplies	28.7	Total waste		28.7

For three men on a 14-day flight, a total of 1,205.4 pounds of life support supplies would have to be stored on board if nothing were recycled. Additional oxygen would be needed if the cabin were depressurized. Because the weight of life-support supplies must be kept to a minimum on a spacecraft, measures are being taken to recycle more of these supplies. Oxygen is already partially recycled. Here only the water and food supplies are considered.

WATER.—The second largest weight requirement for life-support supplies is that for water. The minimum requirement for drinking and hygiene is 4.7 pounds per man per day. Some progress has been made in the reuse of water supplies. Water vapor from the atmosphere is condensed and can be used in the cooling system, as noted earlier. On the Apollo spacecraft, this additional water had to be used only when the heat in the space cabin reached a high level. On the Apollo spacecraft water was plentiful by space standards.

A supply of water was provided by the **fuel cells.** These cells, developed especially for use in space, caused some problems on the Gemini flights when they were being tested, but they have worked well on the Apollo spacecraft. The cells combine oxygen and hydrogen to produce electricity and drinking water as a byproduct. The three fuel cells used on the Apollo spacecraft normally produce a total of about a gallon of water every 5.5 hours. This water is stored in tanks and used for drinking and for preparing food. In addition to the recycled water, a supply of water is brought on board in storage tanks.

Water was plentiful on the Apollo flights because it was carefully managed and was used sparingly. Only small amounts were allowed for washing and hygiene, and no clothes were washed on board. The Skylab will allow more space for carrying water, and the allowances for personal hygiene will be much larger, but no laundry will be done on board. All fresh changes of clothing will be brought along, and the soiled clothing will be placed in containers and stored on board.

FOOD.—The daily requirement for food is the smallest of the three life-support supplies. At present food is not recycled, but a special effort has been made to keep the food served on the spacecraft as lightweight, compact, and nutritious as possible.

The weightless environment creates special problems in storing and consuming food. Ordinary dry foods would crumble when eaten in space, and the crumbs would float about the cabin. The liquids would escape from an ordinary cup or glass and break up into droplets that would also float about. For this reason all foods and beverages for space diets are especially prepared and packaged.

In addition, the calories allowed in the diet take the astronaut's scheduled activity into account. An astronaut who spends all his time in the cramped quarters of the spacecraft is forced to be relatively inactive, but the astronaut who performs EVA burns up much more energy and requires more food calories. American space menus have provided 2,800 to 3,200 calories per man daily.

For the space diet, foods are selected that are low in crude fiber and that are not likely to cause gas in the stomach and intestines. The test pilots who went to very high altitudes soon learned to watch their diet carefully before a flight, avoiding foods that tend to form gas. The astronauts have their traditional steak breakfast on the morning of takeoff.

On the Apollo flights the diet was made up of a wide variety of **freeze-dried foods.** With the water removed from the food, an 80-percent weight reduction was possible. Water guns loaded with fuel-cell water were used to replace the water that had been removed; hot water was used to prepare hot foods, cold water for cold foods. To make housekeeping easier, the freeze-dried foods were packaged in spoon-and-bowl containers. Liquids were taken from closed squeeze containers. Cookies and dry foods were packaged in containers that were edible. Space foods were attractively prepared.

Improved new methods have been used for processing and packaging space foods, and greater variety has been provided in the menus. On the early flights, foods in paste form were squeezed from a container.

The **paste foods** were not too palatable and did not offer much variety. Both **bite-sized foods** and freeze-dried foods were tried on the early Gemini flights. When the astronauts showed a decided preference for the freeze-dried foods, these were adopted for the remaining Gemini flights and for the Apollo flights. On the Apollo flights foods such as sandwiches and dried fruits were added.

On the Skylab, the space and weight allowance for food for each astronaut has been more than doubled over that on the Apollo flights. Meals on the Skylab seem more like those served by the commercial airlines. Hot food is served at the table and eaten with knives and forks (Fig. 73).

Waste Management

For flights planned in the immediate future, no attempt will be made to recycle human wastes to produce food. Research on such recycling continues, however, as described in Chapter 6, and efforts are being made to improve waste management.

Up to the present time the goal in waste management has been simply to reduce the wastes stored on board a spacecraft to the smallest amounts and make them as harmless as possible. Liquid wastes can be dumped overboard and allowed to dissipate in space, but no solid wastes are dumped, as these would continue to orbit and would pollute the environment.

After the medical samples were taken, feces from the spacecraft's crew were collected in special plastic bags, in which a packet of germicide was dissolved. The urine was collected in plastic bags fitted into the space suit or in the spacecraft's urinal. After the urine samples were set aside, the remaining urine was dumped overboard. In space the urine first freezes and then evaporates.

Other solid wastes that accumulated on the spacecraft were sealed in bags or other containers. Leftover food was first treated with a germicide to kill bacteria causing decay and odors. The Apollo astronauts had to work especially hard to keep the command module clean. The dust from the moon, which clung to

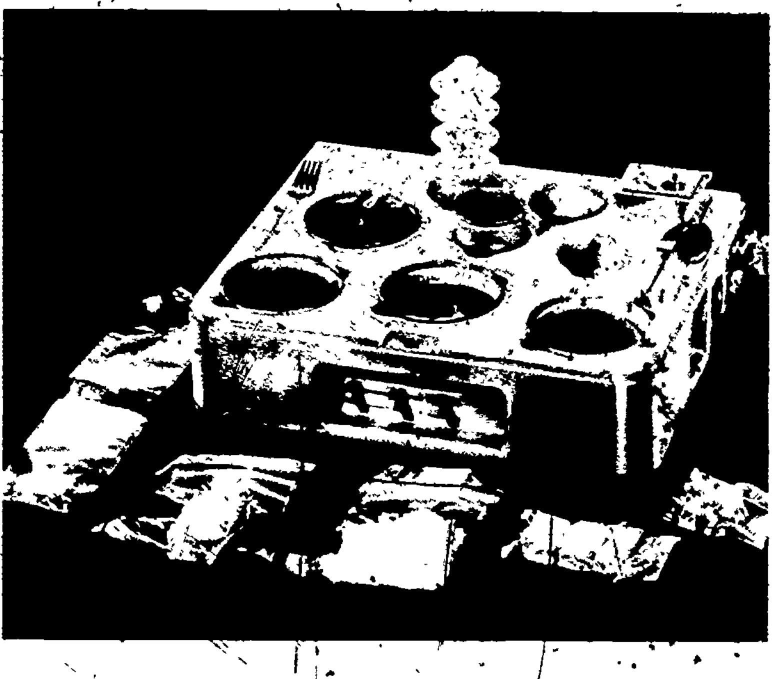

Figure 73. Skylab space food. The food tray is to be used for serving both hot and cold foods.

everything it touched, had to be removed from the moon suits, the sample boxes, and all items brought from the lunar module into the command module.

On the Skylab, modified toilet facilities, provided in the waste compartment (Fig. 74), are especially designed to allow for the regular collection of urine and fecal samples. The samples will be analyzed in an effort to find out how the body adjusts to extended periods of weightlessness. All remaining fecal material, trash, and other wastes are placed in a large tank below the first floor of the Skylab. Access to the tank is obtained through an airlock located in the middle of the floor.

Figure 74. Waste compartment on mockup of Skylab. Note the handholds and other restraints for keeping the astronauts in position during weightlessness

Day-Night Cycle

As the astronauts adjusted to the new routines of life in space, they could not anchor their living to the normal sunrise and sunset, or the familiar 24-hour **day-night cycle** of the earth. In the lower earth orbits the complete day-night cycle lasted only 90 to 100 minutes, as the astronauts made a complete revolution of the earth during this time. On the moon the astronauts saw daylight continuously during their stay because their landings were made during the two-week daytime period.

Since the earliest spaceflights were brief, little adjustment had to be made to the changed day-night cycle. By the time the Gemini flights began, the astronauts settled down to a routine for living in space in preparation for the endurance flight, which was to last two weeks. At first the two Gemini astronauts took turns standing watch and sleeping, but the plan did not work well. In the close confines of the spacecraft, sleep was disrupted by every movement or sound against the background of the deep silence of space.

Following the astronauts' suggestions, space officials decided that it was best to keep all members of the flight crew on the same schedule insofar as possible. This schedule matches the day-night cycle at the Lyndon B. Johnson Space Center (formerly Manned Spacecraft Center) near Houston, Texas, which is the home of the astronauts.

The astronauts' adjustment to the day-night cycle when removed from the earth continues to fascinate biologists. Since ancient times it has been known that living things on earth adjust their physiology to the 24-hour day-night cycle. The adjustments go far beyond the familiar ones of wakefulness and sleep. A mysterious biological clock seems to regulate basic changes in physiology, such as the pulse and respiration rate, oxygen consumption, and the secretion of the glands. So far the astronauts' bodies seem to have retained the 24-hour day-night cycle of the earth no matter where they have been in space. Apparently the astronuats can get by with less sleep in orbit, but this is probably explained by the relaxed condition of the body during weightlessness rather than by any change in their normal 24-hour day-night cycle.

Medical Monitoring

Because there were many unknowns about the way in which the human body would adjust to spaceflight, each astronaut has been fitted with instrumentation for **biomedical monitoring**. The sensors for the system are attached to the skin (Fig. 75). No

Figure 75 Biomedical sensor Two electrodes were placed on Astronaut Frank Borman's scalp to record brain activity during weightlessness. Data recorded was telemetored to earth.

sensors are allowed to penetrate below the skin because of the danger of infection. Readings from the skin sensors are transmitted to miniaturized radio equipment contained in the **biomedical instrumentation belt** worn by the astronauts. Biomedical data is then **telemetered,** or transmitted by radio, to the earth. Biomedical instrumentation has allowed doctors on the earth to make regular direct, or real-time readings of the astronaut's heart and respiratory rate. Using the same equipment, ground control can receive readings of blood pressure, body temperature, and electrocardiograms (electrical recording of heartbeat). When the astronauts are subjected to added mental or physical stresses, doctors closely monitor the biomedical instrumentation.

The primary purpose of biomedical instrumentation is to assure the astronaut's safety and well being. If biomedical data telemetered to the earth were to show that an astronaut's health is endangered, the flight would be terminated. Biomedical data serves another purpose. The vast amount of such data already collected will enable scientists to reach a better understanding of spaceflight. Medical monitoring of the Skylab astronauts will add to this knowledge.

The astronauts have another means of keeping in touch with their doctors during flight. A private communication line is kept open for medical consultation should this become necessary.

In spite of all the precautions taken before flight time, the astronauts have developed colds and other minor illnesses during flight. Germs spread quickly within the closed confines of the spacecraft, as was shown during the early Apollo flights. American medical authorities discourage use of drugs during spaceflight, as even the commonly used drugs may have strange side effects in the alien environment of space. But when the astronaut's doctor advises medication, the astronaut takes the prescribed dosage from the medical kit. The contents of the kit are varied according to the estimated needs of the flight. There will be a doctor in the first crew to visit the Skylab.

Mental Stresses

When animals were rocketed into space, they had to endure severe stresses, but they were unaware of the possible dangers. Each astronaut takes off on his flight with full knowledge of the dangers that lie ahead. Colonel Stapp, in describing the stresses faced by the astronaut in his small spacecraft, points out how well Shakespeare's Hamlet speaks for him: "O God! I could be bounded in a nutshell, and count myself king of infinite space, were it not that I have bad dreams." Although the astronauts have great confidence in their spacecraft and in the ground crews that support them, they are naturally subject to the bad dreams and fears that anyone would be who faces the unknown.

Before spaceflight began, scientists were concerned that the astronauts, inclosed in their space capsule and shut off from all sense perceptions from the outside, would suffer from isolation. The first astronauts, who orbited in the Mercury, were alone in the spacecraft. To get some idea of how astronauts might react to isolation and confinement in space, scientists made simulated cabin tests on the earth. In these tests subjects frequently suffered from mental stress and experienced hallucinations.

In spite of the many **mental stresses** to which the astronauts have been subjected, they have been able to adjust to them. They have remained calm and in control of the situation even under the threat of serious danger. A doctor assigned to ground control monitors the circuit to be able to judge the mental condition of an astronaut by the tone of his voice.

One cause for mental stress during spaceflight is the fact that an astronaut knows that he cannot escape from a disabled spacecraft during flight. To reduce the hazards of spaceflight, scientists and engineers are trying to develop some means for space rescue.

SPACE RESCUE

After the oxygen tank in the service module exploded on the Apollo-13 flight, the astronauts were able to make a safe return to earth by using the lunar module as a "lifeboat," but the astronauts could have been stranded in space. This realization caused the United States and the Soviet Union to renew their efforts to devise means for **space rescue** and prompted them to work together toward this end. In order to cooperate in space rescue, both nations must use the same or similar kinds of breathing atmosphere, and their spacecraft must be equipped with docking collars that fit together and work interchangeably. This need for cooperation has led to a freer exchange of information on space biology and medicine. It has also resulted in a plan to have a joint docking of a Soyuz and an Apollo spacecraft with an interconnecting airlock module. The linkup will not be made until the Skylab visits are completed.

The American spacecraft have been equipped with escape devices to rescue the astronauts in case trouble should develop in the booster at launch time. The Gemini spacecraft was equipped with ejection seats similar to those used on jet aircraft. The Mercury and Apollo spacecraft had a **launch escape tower** attached to the astronaut's module, or the reentry module (Fig. 76). The escape tower was powered with a rocket engine that could be fired automatically to take the reentry module out on a trajectory over the Atlantic Ocean downrange from the launch pad. The module could be recovered by use of a parachute and then splashdown in the ocean. Rescue teams go through drills to prepare them for recovering the astronauts from the ocean should this be necessary. The launch escape devices developed for the astronauts have provided engineering know-how for making improvements in zero-level recovery devices for pilots of jet aircraft.

For added protection, all astronauts are thoroughly trained in emergency procedures, and the spacecraft is equipped with **redundant systems,** or extra systems, for use in case one system malfunctions. On the Gemini-8 flight, when the spacecraft threatened to go out of control, an emergency reentry and splashdown was made with ease, using procedures that had been partially worked

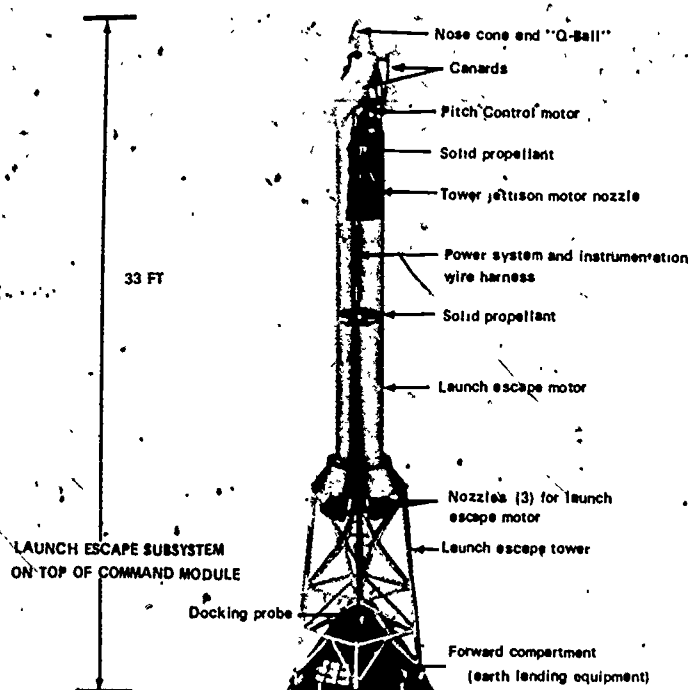

Figure 76. Launch escape system for Apollo command module. The escape system would propel the astronauts away from the launch pad in case trouble developed in the booster.

out in advance. On the first moon landing, Astronaut Neil Armstrong was able to override the automatic systems of the lunar module and delay until he could find a smoother place for landing.

On the first three series of US spaceflights, the **emergency procedures** worked well when needed, and all spacecraft parachuted down safely for splashdown and recovery in the ocean. The tragic fire that took three astronauts' lives occurred on the launch pad during a preflight test, not during an actual launch.

On the Skylab, procedures for rescuing astronauts from space are to be in effect for the first time. After the modified Apollo spacecraft (combined command and service modules) is launched for each visit, an identical Apollo spacecraft is to be placed in readiness for launch. Should the astronauts become stranded in the Skylab during their stay there, the reserve Apollo spacecraft can be equipped with two extra seats by making use of a special kit. Two astronauts would go on the rescue mission to the Skylab, and the spacecraft would return for splashdown with five astronauts (Fig. 77). If the reserve spacecraft is not needed for rescue, it is to be used for the next scheduled visit. For the third and last visit, an additional Apollo spacecraft will be placed in readiness for launch, just as for the other visits, even though the spacecraft

SKYLAB RESCUE CSM GENERAL ARRANGEMENT

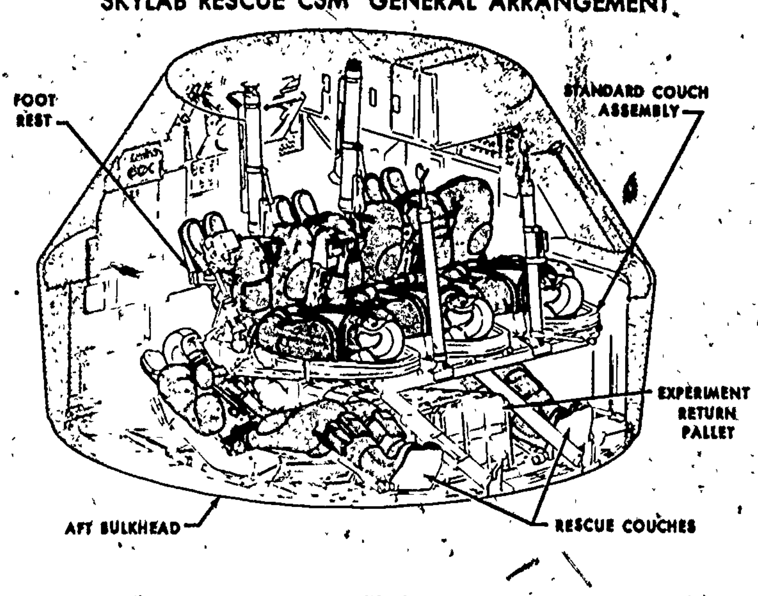

Figure 77. Apollo command module modified for rescue mission. The module could bring back five astronauts.

has no flight scheduled for it at that time. The plan will provide for rescue from the Skylab only, but it should take care of emergencies most likely to develop.

Before considering what we might expect to learn about spaceflight from the Skylab visits, it would be well to review the findings about man in space made on the first three series of spaceflights. This is done in the following chapter.

TERMS TO REMEMBER

radiation environment
ionizing radiation
particle radiation
solar-flare particles
charged particles trapped in the Van Allen radiation belts
galactic cosmic rays
shielding against space radiation
rad
meteoroids
micrometeoroids
meteorite bumper
weightlessness
weightless trajectory
artificial gravity
transverse G-forces
heat shield
manrate (a missile)
shirt-sleeve environment
environmental control system
lithium-hydroxide canisters
radiator (in a spacecraft)
radiation (of heat)
oxygen poisoning
mixed-gas atmosphere
space suit
EVA suit
space undergarment
moon suit
Portable Life Support System (PLSS)
umbilical
open life-support system
semiclosed life-support system
life-support supplies
fuel cells
space diets
freeze-dried foods
paste foods
bite-sized foods
waste management
day-night cycle
biomedical monitoring
biomedical sensors
biomedical instrumentation belt
telemetered medical data
mental stresses
space rescue
launch escape tower
redundant systems
emergency procedures

QUESTIONS

1. At what altitude might space be said to begin for man? What are some of the characteristics of the space-equivalent zone? What causes the utter silence and darkness of space?

2. What are the three new stresses encountered in spaceflight?

3. What are the principal sources of harmful radiation in space? What is believed to be the most dangerous source of radiation?

4. How does the body appear to be affected by weightlessness? What questions about weightlessness are still unanswered?

5. How does the astronaut's reclining position enable him to resist G-forces at launch and reentry?

6. What causes heating of the reentry module? How is the heat counteracted or controlled?

7. What is the principal source of noise in spaceflight? How are astronauts protected against this noise?

8. What is meant by manrating a missile?

9. What is meant by the shirt-sleeve environment?

10. What is an environmental control system and how does it function in a spacecraft?

11. What were some of the new features of the moon suit? How was it cooled?

12. How is water supplied to the Apollo spacecraft?

13. What kinds of foods have been used for US spaceflights? Why have space foods been specially prepared? What kind of food service will be used on the Skylab?

14. How do doctors on earth monitor the astronauts during their flights?

15. What measures have been taken to assure the astronauts' safety during flight? Can an astronaut eject from a spacecraft?

THINGS TO DO

1. Make a study of space radiation. Name the three sources of space radiation that present the greatest potential danger to man in space. Explain what a solar flare is. If information is available, describe the findings made from the experiments carried on Apollo 16 and 17 that exposed mice and other living matter to the light flashes observed by the astronauts. Secure the publications of the US Atomic Energy Commission listed in the "Suggestions for Further Reading" listed below for your study

2. Make a study of weightlessness. Describe your own experiences that have most closely resembled weightlessness. Summarize the most important observations made on the Mercury, Gemini, and Apollo flights concerning weightlessness. How has underwater practice helped the astronauts perform space work more efficiently? What experiments concerning weightlessness are planned for the Skylab visits?

3. Compare the effects of the G-forces exerted on a seated pilot and on a reclining astronaut. Use simple diagrams or models to explain the action of the blood as it is pumped from the heart to the brain and the eyes. Show the approximate location of the heart and of the column of blood that goes from the heart to the brain and eyes, also the main branches of red blood, or oxygenated blood, flowing to the legs. Compare the vertical distance between the heart and the brain in both cases. In which

case does the blood have to be pumped a greater distance? Under the effect of 10 G what happens to the pilot and to the astronaut?

4 Make a study of the environmental control system of the Apollo spacecraft. Concentrate on the oxygen supply. How was oxygen purified? If you have studied chemistry, do some research and explain how the lithium hydroxide canister is able to trap the carbon dioxide. At what times during the Apollo flights was the space suit worn? (For suggestions on setting up an experiment on removing carbon dioxide from a spacecraft, see *Activities in Science Related to Space*, page 23, published by NASA and listed in the references below.)

5 Make a study of the Apollo moon suit. Use a simple diagram or model to demonstrate the operation of the suit. Show the white coveralls (the Integrated Thermal Micrometeoroid Garment—ITMG). What was worn under the coveralls? How was the moon suit cooled? How was it supplied with fresh oxygen?

6. If you are interested in foods and nutrition, make a study of the kinds of foods used on US spaceflights to date. Which kind of food has been used most often and has proved most palatable? What kinds of new foods were introduced on the Apollo flights? Make up a set of sample menus for the astronauts for two or three days during an Apollo flight. Why was potassium added to the astronauts' diet on Apollo 16 and 17? How did it affect the astronauts? Find out what you can about the food service on the Skylab.

7. Make a study of waste management on the Apollo flights and on the Skylab. How is research on waste management in space related to pollution problems on the earth? NASA is doing research that should help small communities improve their handling of sewage and thus help to prevent pollution of rivers and streams.

8. Make a study of medical monitoring. Describe one or two of the medical sensors used for telemetering biomedical information. Explain how the system collected biomedical data and relayed it to the earth. Use a simple block diagram to explain the system. (Concentrate on the biomedical information obtained rather than the engineering of the system.) How was the biomedical instrumentation belt used? Why were all the medical sensors kept on the skin and not implanted?

9. Describe the plans made for rescue from the Skylab. How can five astronauts be accommodated in the Apollo command module? What progress has been made in joint American-Soviet efforts to develop a means of rescuing astronauts and cosmonauts from space?

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THIS CHAPTER outlines the biomedical findings made on the first three series of American manned spaceflights (Mercury, Gemini, and Apollo flights), and it explains how the Skylab visits should enable us to learn more about man's ability to live and work in space. After you have studied this chapter, you should be able to do the following: (1) describe the most important biomedical finding made on the Mercury flights; (2) explain two ways in which the Gemini-7 astronauts' bodies were kept in good condition during their 14-day flight; (3) tell how the Apollo astronauts were protected during EVAs on the moon; and (4) name the most important stress of spaceflight to be studied in the Skylab, and describe three of the biomedical experiments to be conducted.

IN SLIGHTLY more than a decade of manned spaceflight, American astronauts have made a total of 27 spaceflights during the Mercury, Gemini, and Apollo programs. During these flights they have progressed from earth orbital flights to moon orbital flights and landings on the moon. Now that the first three series of spaceflights have been completed, American astronauts have turned their attention to earth orbital flights again. With the launch of the Skylab into earth orbit, the United States has a temporary space station in which astronauts can extend the time spent in space. While in the Skylab, the astronauts will conduct biomedical experiments designed to give us some answers to questions raised on the first three series of flights.

FIRST THREE SERIES OF FLIGHTS

Since astronauts are subjected to much greater flight stresses than aircraft pilots are, the selection standards for astronauts are even higher than those for pilots. All astronauts have to be jet pilots, and they have to meet even more rigid physical requirements than aircraft test pilots. In considering how well the astronauts have met the requirements of spaceflight, one must remember that they are men who have exceptional mental and physical qualifications.

In the course of the spaceflights, many astronauts have made more than one spaceflight, and some have made as many as three or four such flights. As a result, US scientists have accumulated a body of data about individual astronauts and a variety of data about man's physical and mental responses to spaceflight.

From an operational standpoint, the climax of US. manned spaceflight came during the Apollo flights when the astronauts first landed on the moon. From a biomedical standpoint, the climax of the flights came during the Gemini flights when the American astronauts spent their record 14 days in space. A period of 14 days would allow a margin of safety for the trip to the moon and stay-time on the moon for exploration. As the astronauts progressed from the Mercury flights through the Gemini flights and to the Apollo flights, they were gradually meeting the human requirements for a trip to the moon and for a longer stay-time and extended EVA on the moon.

Mercury Flights

The Mercury flights showed that man could survive the high G-forces and other rigors of launch and reentry and that he could eat, drink, and sleep during the weightless condition. The first fears about man's reactions to spaceflight were laid to rest, and it was shown that man has a place as a pilot in spaceflight. On the first orbital flight when three systems in the spacecraft malfunctioned, Astronaut John Glenn took over manual control, and permission was given to continue the flight for three orbits lasting about four hours. Time in flight was gradually increased until, on the last Mercury flight, Astronaut Gordon Cooper remained in orbit for a day and a half.

On his flight Astronaut Cooper made remarkable observations of the earth from orbit. He reported that he could see whiffs of smoke coming from chimneys in Tibet, trace roads, and observe the wake of steamers on the Nile River. Cooper's medical record shows that he had extremely high visual acuity, but later other astronauts also made acute observations of the earth, and photographs taken in space confirmed their reports. Away from the obscuring effects of the earth's atmosphere, a man in low earth orbit can easily spot mountain ridges, great rivers, forest stands, and ocean shorelines with the naked eye.

The Mercury astronauts had little time for making observations during most of their flight. They had many tasks assigned to them, and other tasks developed in emergencies. Since there was only one astronaut on each flight, he had to exert himself and was often too absorbed in his duties to eat and drink regularly Sometimes the environmental control system did not channel off the heat rapidly enough as it built up. Consequently, the Mercury astronauts returned from their flights tired and dehydrated. All astronauts lost weight on their flights. At first this was believed to be caused by loss of body fluids, but the loss in weight continued through the Gemini flights and even on the Apollo flights when there was an abundance of drinking water, indicating that it is probably a reaction to the stresses of spaceflight.

During the last two Mercury flights, which were longer, the astronauts began to show the effects of continued confinement (Fig. 78) and exposure to the weightless condition in orbit. The circulatory system appeared to be affected most, but there was also a general deconditioning of the muscles. While in the weightless condition, the astronaut's circulatory system was not subjected to the normal gravity force. When the astronaut returned to the earth and the normal gravity condition, his heart

Figure 78. Mercury astronaut confined in spacecraft. The first sub-orbital flight of Astronaut Shepard (above) lasted only 15 minutes. On the last Mercury flight Astronaut Cooper was in the cramped quarters of the spacecraft during a flight lasting a day and a half.

and circulatory system seemed to be affected. Astronaut Cooper staggered noticeably when he tried to walk after being recovered. All Mercury astronauts were normal again within about 24 hours after recovery, however, and their flight surgeon could give the go-ahead signal for longer flights.

Gemini Flights

On the Gemini flights, time in orbit was increased from about 4 days on Gemini 4 until finally, on Gemini 7, Astronauts Frank Borman and James Lovell made the 14-day American endurance record. The most extensive biomedical experiments were made on the Gemini 7.

One of the experiments that flight surgeons conducted aboard the Gemini 7 was designed to find out whether the astronauts gradually lost small amounts of calcium from their bones during weightlessness. Such a loss of calcium is known to occur in sick persons who are confined to their beds for a period of time. The condition is accompanied by general weakness and a loss of muscular tone. To study calcium loss during weightlessness, the astronauts' heel bones and one bone in the right little finger were used. These bones were X-rayed before and after the flights. After a careful study of the medical data, flight surgeons concluded that the astronauts did lose small amounts of calcium from their bones during weightlessness.

To keep their bodies in condition while in orbit, Astronauts Borman and Lovell exercised three times daily by pulling on rubber cords. This exercise was adequate to stimulate the flow of blood and make the circulatory system work in spite of weightlessness. With exercise, the muscles were also kept in tone. Later the astronauts readjusted more readily to normal earth gravity.

When Astronauts Borman and Lovell were recovered after their 14-day flight (Fig. 79), they seemed to be in even better condition than the astronauts were after the 8-day flight on the Gemini 5. It was evident that the measures the Gemini-7 astronauts had taken to keep their bodies in condition during weightlessness had been successful. The excellent physical condition of the astronauts on the record flight was also believed to be due to the greater comfort they enjoyed when they removed their space suits and relaxed in the shirt-sleeve environment.

Even with the exercise program followed on the Gemini flights, there was some indication that the astronauts' heart and circulatory system were affected by weightlessness. None of the Gemini astronauts experienced dizziness or staggered upon leaving the capsule, however, even though they had spent a longer time in orbit than the Mercury astronauts.

The Gemini astronauts could adjust better to the weightless condition and to spaceflight in general because they had the experiences of the Mercury flights to build upon, and they had more time in which to set up a regular routine for living in space. When the astronauts were able to get regular periods of sleep, enjoy regular meals, and take plenty of drinking water, they did not become fatigued and dehydrated during flight. Also, the environmental control system worked more efficiently on the Gemini than on the Mercury flights. As a result, the astronauts' space suits did not overheat as long as they were inside the Gemini spacecraft. Then, too, since two astronauts were on board, the Gemini astronauts could take turns at piloting and share other

Figure 79. Gemini astronauts after recovery following 14-day flight. Astronauts Frank Borman (right) and James Lovell are shown as they walked on the deck of the recovery ship.

tasks. Consequently the workload was more realistic, and emergencies could be handled better. On the Gemini flights the astronauts seemed to be well on their way toward adjusting to living in space.

As was to be expected, the astronauts' heartbeat increased during times of stress and exertion, such as at takeoff and reentry, and during EVA. What was not expected was that the heartbeat of normal, well persons would reach the high levels that the astronauts' did at times during the flights. Astronauts Eugéne Cernan and Richard Gordon, during extended EVA, exerted themselves so much that their EVA suits overheated and water vapor accumulated in their helmets. More realistic goals were set for the space work on the last Gemini flight, Gemini 12.

The great amount of energy required to perform space work arises partly from the need to establish a firm position to give the astronaut leverage. When he pushes on a lever or turns a screw in orbit, he creates a reaction force. According to Newton's third law of motion, for every action there is an equal and opposite reaction. In orbit there is no gravity force to offset the reaction force and hold the astronaut in position. Astronaut Michael Collins, who performed EVA on the Gemini-10 flight, said: "A considerable part of my attention was devoted to holding my body in the proper position to do the best work. I found I usually overshot or swayed back and forth. I was never absolutely motionless. I was continually moving whether I wanted to or not."

Astronaut Edwin Aldrin, wearing a much improved EVA suit on the Gemini-12 flight, was able to complete his space tasks successfully (Fig. 80). Aldrin also had more handholds, and they were better placed. Further, he had gained skill by simulating space work while training underwater. All his efforts pointed to the need for special training for space work, for special tools, and for experiments to study the processes that take place in the body as space work is performed.

The Gemini flights showed that the goals for EVA on the Apollo flights could be met, and the changes that occurred in the body during the Gemini flights were not large enough to cause concern for the astronauts' safety.

Apollo Flights

During the Apollo flights the astronauts continued to show physiological changes even though they could move about more freely in the command module, but the crews in general adapted better to the weightless condition. In fact, the Apollo astronauts seemed to have learned how to use weightlessness to their advantage. The schedules for work and sleep were improved somewhat, but losses in body weight continued.

On the Apollo flights man for the first time left the protective cover of the earth's magnetosphere and was exposed to the radiations from space. The astronauts who landed on the moon reported that they saw light flashes, which are believed to have been caused by cosmic rays. The astronauts could see the light flashes even when they experimented with putting masks, or blinds, over their eyes. The high-energy cosmic rays seemed to have penetrated the wall of the spacecraft and the eyes of the astronauts and registered as light flashes on the retina of the eye. Apparently no harm was done by the radiation because it was not abundant.

Some experimenters on the earth report that they can sense the presence of ionizing radiation by an itching of the skin, but there is no reliable way to detect harmful radiation through the senses. To take advantage of the unique opportunity for observing what are believed to be cosmic rays while outside the

Figure 80. Astronaut Edwin Aldrin during EVA on Gemini-12 flight. Aldrin is carrying a micrometeoroid package to the spacecraft. He removed the package from the outside of the spacecraft.

earth's magnetosphere, the astronauts on the Apollo 16 and 17 took with them samples of living matter to expose to the radiation. The astronauts on the Skylab do not expect to see the light flashes because the Skylab will remain in earth orbit. Soviet cosmonauts have not reported seeing similar light flashes, but they have not as yet gone beyond earth orbit.

Fortunately for the Apollo astronauts, none of them was exposed to intense dosages of solar-flare particles. Although the flights were made close to a period of peak sunspot activity, no flights were made at dangerous times. Doctor Berry reported that the astronauts on Apollo 15 were exposed to a minor solar flare, but they received a radiation dosage of only about 0.5 rad, a harmless amount. None of the astronauts received significant amounts of radiation in passing through the Van Allen radiation belts.

The astronauts were also spared any impacts by meteoroids while they were on the moon. The seismographs that the astronauts left on the moon have recorded some meteoroid impacts since the first landing.

During the Apollo flights the astronauts gradually extended total stay-time and the time spent in EVA on the moon. From the single EVA lasting about 2.5 hours, made by Astronauts Neil Armstrong and Edwin Aldrin on the first moon landing, the astronauts progressed to three EVAs totaling 22 hours 5 minutes on the Apollo 17, the final flight. During the final three EVAs on the moon, Astronauts Eugene Cernan and Harrison Schmitt came close to the limits of the life-support supplies provided by the moon suit and backpack.

On the Apollo-17 flight the lunar rover worked well, and the astronauts followed carefully scheduled periods of work and rest. In addition, some potassium was added to their diet, just as on the Apollo-16 flight, in order to keep the body fluids in better balance.

During EVA on the moon (Fig. 81), astronauts expended large amounts of energy, just as they did during EVA in space. Although they had gravity to help them on the moon, they performed heavier work. For this reason the astronauts were carefully monitored on the moon to make sure that their expenditure of energy did not exceed safe limits. Energy expended was measured either by recording heartbeats or by taking into account the amount of heat generated within the moon suit. Although Astronauts Cernan and Schmitt, on the final flight, made the most extensive exploration and gathered the largest supply of rock samples, they did not overexert themselves and were in excellent physical condition when recovered.

Figure 81. Astronaut James Irwin during EVA on moon. Irwin is collecting rock samples.

As the astronauts moved about on the moon, they learned to adjust to the reduced gravity force, which is about one-sixth that of earth gravity. In making the kind of leaps or long strides allowed by the reduced gravity, the astronauts were at first prone to lose their footing on the slippery surfaces. This caused some concern because a fall could have resulted in rupturing the moon suit and bringing about fatal decompression. In time the astronauts learned to right their movements, regain their balance, and prevent falls.

Although the possibility was remote that the astronauts might become infected with an alien organism on the moon, there was some fear that this might happen and that the astronauts would bring the organism back and infect the earth. For this reason the astronauts were carefully quarantined after the first three moon landings. The most rigid restrictions were observed. The swimmer who entered the command module upon recovery wore an isolation garment to protect him against infection, and he handed similar garments to the astronauts for them to put on. When the astronauts came aboard ship in their isolation garments, they went into a box called a **mobile quarantine facility** (Fig. 82). This was airlifted to the Lunar Receiving Laboratory near Houston, Texas. Here the astronauts remained for 14 days of quarantine, along with any persons accidentally exposed. Only after their quarantine period was over could the astronauts receive the welcome that awaited them. After careful testing revealed no signs of even the smallest living organism, quarantine was no longer enforced.

Besides providing a body of unique biomedical data, the US spaceflights have had a much wider influence on the study of physiology and medicine.

Results of the Findings.

As a result of the 27 American spaceflights, it is evident that man can successfully adjust to flights in space for periods of at least two weeks. Many questions still remain unanswered, however, about the two stresses of radiation and weightlessness. Since radiation is not likely to become a problem until man again ventures beyond the earth's magnetosphere and attempts longer trips into space, attention in the immediate future will be focused on finding out more about the effects of weightlessness.

Figure 82. Astronauts in mobile quarantine facility. President Nixon greeted the quarantined astronauts through a closed window. The astronauts who made the first moon landing are (left to right). Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin. Astronauts were quarantined after the first three moon landings.

Certain changes have taken place in the body during orbital flight that are believed to be caused by weightlessness, or zero gravity. These changes were largely in the circulatory system, the muscles, and the bones. The changes were not large enough to cause alarm, and even on the longer flights the body readjusted to earth gravity within about 50 hours after recovery.

Man's ability to adjust successfully to flight at the higher altitudes in the earth's atmosphere, has led to a revolution in transportation. Aviation grew by leaps and bounds until it became one of the most common means of transportation. It is unlikely that there will be a similar movement to space transportation in the immediate future, but man's efforts to cope with the stresses of spaceflight have led to significant developments in areas other than transportation.

The stimulus given to aerospace medicine by spaceflight has led to a revolution in the study of human biology and medicine. Never before in the history of medicine have such detailed studies been made of well persons. By studying the body as it is exposed to the weightless environment, new insight has been obtained into man's physiology. Further, the sensors and instruments developed to monitor the astronauts during spaceflight have opened the way to all kinds of new medical sensors, to new methods of treatment, to entire hospitals built around automatic monitoring of patients, and to the development of artificial organs and implants of them in the human body.

As the Apollo flights progressed, American astronauts began to visit Soviet training facilities, and Soviet cosmonauts were invited to come to American facilities. These visits, together with the need to develop joint methods for space rescue, have led to a much freer exchange of biomedical data between the two countries. Such an exchange has greatly increased the knowledge that both nations have about spaceflight.

In general, Soviet scientists have used the same methods for helping their cosmonauts adjust to the rigors of spaceflight as have our scientists, but there have been important differences between Soviet and American spaceflights, both in methods and in biomedical findings. One of the most important differences is that the Soviets have not used pure oxygen pressurized at lower than atmospheric pressure for their spacecraft. Instead they have used a mixed gas resembling the earth's atmosphere, which is pressurized at about 14.7 psi. Then, too, Soviet cosmonauts have experienced some nausea and disorientation during weightlessness, and the cosmonauts have required longer periods before returning to normal after their longer flights.

The big question that now faces scientists is, What will happen to man during longer periods of spaceflight? The American Skylab should provide a means for getting some answers to this question.

THE SKYLAB

As the Apollo flights were completed, the Skylab was put into readiness for launch. The Skylab, developed from the empty third stage of the Saturn V booster, is the largest space ship yet launched. It is four times larger than the first Soviet Salyut (Salute).

The Skylab was launched into a nearly circular orbit on 14 May 1973 at a distance of more than 270 miles from the earth and at an inclination of 50 degrees to the equator. The orbit is far enough from the earth to maintain stability and close enough to the earth to be clear of harmful radiation from the Van Allen belts. When launched, the Skylab contained all the food, water, and oxygen needed to support the entire mission.

After the Skylab was in orbit, the two large solar panels for developing electrical power for the workshop failed to deploy, and it was found that the meteoroid and heat shield had been torn off at launch. As a result, the Skylab heated. Temperatures inside the spacecraft averaged 120 degrees F. and even reached 190 degrees. Because of the high temperatures and loss of power, launch of the first crew was delayed until 25 May. Time gained by the delay was used to design a substitute shield and test procedures for deploying it. Plans were made to have the astronauts maneuver around the damaged workshop to inspect it, and then perform EVA to deploy the new shield. Because of the time required for making repairs and the loss of power, the astronauts could perform fewer experiments, but they would have an opportunity to demonstrate how well men could work in space. The Skylab missions would present a real test of both men and systems.[1]

Living Quarters and Laboratory

The main unit of the Skylab, the combined living quarters and laboratory (the workshop), contains about as much space as a three-bedroom house. With the large amount of room allowed,

[1]After this book went to press, the Skylab 1 astronauts made their visit and completed a 28-day period in the workshop. During their stay the astronauts deployed an umbrella-like shield to protect the workshop from the sun, and the temperatures in the workshop dropped. The astronauts were also able to deploy one of the large solar panels, increasing the amount of electrical power for the workshop; the other large solar panel had been sheared off. By successfully making repairs, the Skylab 1 astronauts left the workshop in a satisfactory condition for future visits.

the three astronauts in each crew can live more nearly as they do under earth conditions. The Skylab contains a dining room (wardroom), individual sleep compartments, and toilet facilities (waste compartment), as shown in Figure 83.

Moving about in the Skylab is much easier than moving about during EVA in space. Many handrails are provided in the Skylab to control the motion. Also the astronauts can walk on the floor or ceiling by making use of special cleats on their shoes that fit into the open meshes in the floor and ceiling.

The astronauts have restraints, or "hold-downs," to keep them in position while eating in the wardroom or while using the waste compartment or sleeping. The astronauts stand at the table and are held in place by foot and thigh restraints (Fig. 84). Their trays are secured with magnets, and they use knives and forks. The sleeping restraints resemble sleeping bags placed on the wall and

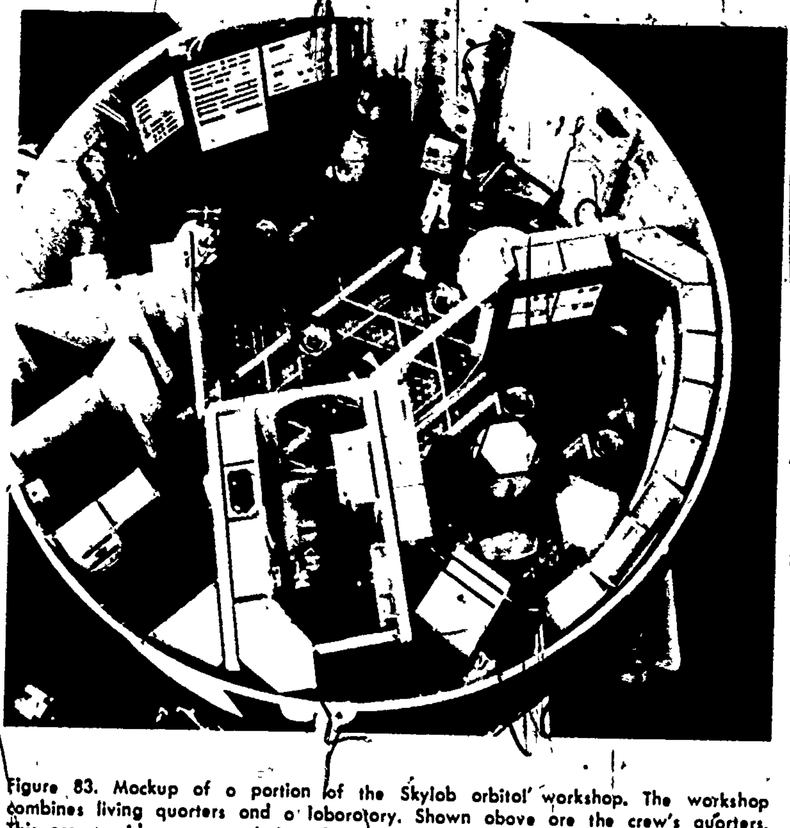

Figure 83. Mockup of a portion of the Skylab orbital workshop. The workshop combines living quarters and a laboratory. Shown above are the crew's quarters. This area provides accommodations for sleeping, preparing and eating food, hygiene, waste management, and performing some medical experiments.

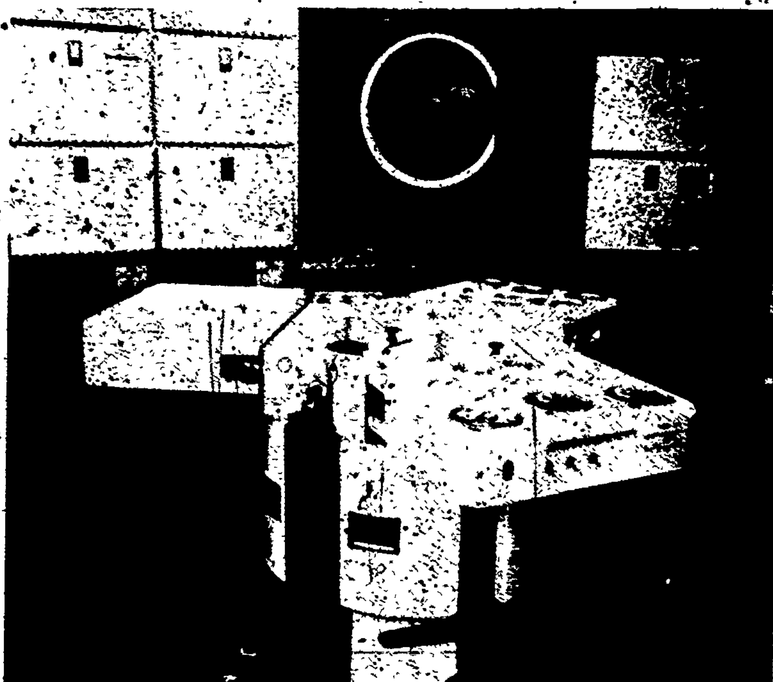

Figure 84. Table in mockup of Skylab. The table is made up of the three trays used for serving food to the astronauts. Note the restraints for holding the astronauts in position while they eat.

the astronauts sleep in a vertical position. Usually the astronauts wash with moistened terry cloth washcloths, but a shower is available for use once a week. The astronauts assigned to the Skylab are asked to evaluate its habitability. Their observations will guide engineers in designing future space vehicles and equipment for living in space.

The breathing atmosphere in the Skylab is no longer pure oxygen but oxygen diluted with nitrogen (about 30 percent nitrogen to 70 percent oxygen). The total pressure of the two gases is the same as that of the atmosphere used in the Apollo spacecraft for the moon flights, or about 5 psi. Unlike the Apollo spacecraft, the Skylab has a special airlock module that allows the astronauts to go outside for EVA without depressurizing the space cabin. The Skylab space suit resembles the moon suit (Fig. 85).

Mission and Biomedical Experiments

The launch of the Skylab marked the beginning of US efforts to conduct scientific research in orbit. The Skylab is a temporary space station, or what might be called an experimental space station.

Experiments are being conducted in the Skylab in two other areas besides the life sciences: astronomy, or mostly studies of the sun; and applications, principally studies or surveys of earth resources from orbit and of manufacturing processes in zero gravity. Of more than 50 experiments, some 16 experiments will be devoted to the life sciences, but in a larger sense the subject of all experiments in the Skylab is man in space.

Figure 85. Skylab space suit and maneuvering unit. This maneuvering unit is scheduled to be tested inside the Skylab workshop.

While the astronauts are conducting other experiments in the Skylab, they themselves are producing data about man's physiological and mental reactions to living and working in space for longer periods. The earlier spaceflights pointed up the fact that during periods up to 14 days in space certain basic changes took place in the body. These changes were small but measurable. During longer periods in space will other changes become evident that were too small to be measured during a 14-day flight? The hows and whys of various changes now become important questions.

The Skylab represents another important step in studying man's adaptation to flight. Some conditions of spaceflight can be simulated on the ground, but there is no way to duplicate all the conditions of space except in space. Weightlessness can be produced on the earth for only a matter of seconds during a weightless trajectory, as explained earlier, and this amount of time does not permit conducting the kind of experiments now called for.

On the Mercury, Gemini, and Apollo flights, scientists could collect biomedical data through telemetry, but these flights had an operational mission. When medical data was not needed to assure the astronauts' safety, it could not be collected if doing this interfered with the operational mission. The Skylab has no mission other than to conduct experiments in orbit.

To achieve longer periods in space, time will be at first doubled. The first mission in the Skylab is scheduled for 28 days, or twice the time spent in space during the Gemini-7 flight. On the second and third Skylab missions the astronauts are to spend more than double the time of the first mission.

Of the 16 life-sciences experiments planned for the Skylab, 6 are to consist of detailed measurements made on the ground before and after the flights to the Skylab, thus pointing to the changes that occurred during orbital flight. The other 10 experiments concern living in space itself, and one set of experiments is related to the other. The circulatory system, muscles, bones, and body fluids will be studied. Changes in these are to be compared with weight losses and with changes in the body's metabolism, or the process of building up tissue and using food. The studies of metabolism should help to explain why astronauts have different nutritional needs in space than they do on earth. Finally, there will be a series of experiments conducted on the balance mechanism in the inner ear (semicircular canals and otolith organs). Time and motion studies of the body's balance mechanism made on the Skylab will be the first studies made of this mechanism when the gravity stimulus is absent. The bicycle ergometer (Fig. 86) and the lower body negative-pressure cham-

Figure 86. Astronaut Joseph Kerwin on bicycle ergometer. The ergometer can be used to test man's effectiveness while doing mechanical work after a stay in space. The equipment can also be used for exercise to keep the body in condition during weightlessness.

ber (Fig. 87) are special equipment for conducting medical experiments on the Skylab.

To help students and teachers appreciate the importance of the space environment for scientific research in the future, NASA invited high school students to submit ideas for experiments to be carried out on the Skylab. More than 3,400 students responded, and 25 experiments were selected. As many student experiments as time and space permit are to be carried on the Skylab. Among the experiments selected was that of Cadet Lyndon D. Long, an Air Force Junior ROTC cadet from Southern High School, in Graham, North Carolina.

Crews for the Skylab

Each crew for the Skylab is made up of one scientist-astronaut and two pilot-astronauts from the active astronaut corps. Astronauts in the corps have been selected on two bases. as **pilot-astronauts** and as **scientist-astronauts**. The scientist-astronaut has to meet the same high physical standards as the pilot-astronaut.

Figure 87. Lower body negative-pressure chamber for use on Skylab. The vacuum in the chamber produces the effects of gravity and stimulates the flow of blood in the lower part of the body. The equipment can be used for medical experiments and for keeping the body in condition during weightlessness.

He must also have a bachelor's degree plus a doctorate, or its equivalent in experience, in the natural sciences, medicine, or engineering Scientist-astronauts who are not qualified pilots when selected must take jet training and become proficient pilots.

The first crew for the Skylab is commanded by Charles Conrad. The pilot is Paul J. Weitz, and the scientist-astronaut is Dr. Joseph P. Kerwin. Astronaut Conrad commanded Apollo 12, and he flew on the Gemini 5 and 11.

The second crew will also be commanded by an experienced astronaut, Alan L. Bean, who flew on Apollo 12. The pilot will be Jack R. Lousma, and the scientist-astronaut will be Dr. Owen K. Garriott.

For the third crew, the commander will be Gerald P. Carr, the pilot William R. Pogue, and the scientist-astronaut Dr. Edward G. Gibson.

Training for Skylab Visits

Training continues for the Skylab visits. Special mission simulators for these flights are located at the Johnson Space Center, and both prime and backup crews are at work on the simulators. The astronauts are becoming familiar with the hardware on the

Figure 88. Astronauts and engineers working underwater with Skylab mockup. Conditions underwater resemble those encountered during weightlessness in space. The full scale mockup is located at the Marshall Space Flight Center in Alabama.

Skylab, especially with the equipment for the biomedical experiments and for routine living. In preparation for Skylab experiments requiring EVA, the crews are practicing underwater (Fig. 88) because conditions underwater most nearly resemble those of weightlessness. Each crew member is to spend at least 1,500 hours in mission training.

As part of their training for the Skylab, crew members take three days of medical instruction at the regional hospital at Sheppard Air Force Base, Texas. Here they learn how to use the Skylab medical kits and make simple examinations. If the Skylab crews can solve their own minor medical problems, they may prevent an emergency return to the earth. The scientist-astronaut on the first crew is a medical doctor.

When the three Skylab visits have been completed, astronauts will be trained to fly the space shuttle and the reusable space vehicles of the future. Findings made on the Skylab should tell us much about spaceflight in the future.

TERMS TO REMEMBER

mobile quarantine facility

experimental space station

pilot-astronauts

scientist-astronauts

QUESTIONS

1. What important findings were made about man's ability to live in space on the Mercury flights? What did we learn about man's ability to pilot a spacecraft?

2. Why were the Gemini flights important in adapting to spaceflight? What was the American record of endurance made during the Gemini flights? How did the astronauts counter the effects of weightlessness?

3. Why did the Apollo astronauts expend large amounts of energy during EVA on the moon? Explain how the astronauts received life support on the moon.

4. What is the Skylab? Name three important ways in which living conditions in the Skylab differ from those existing in the Apollo spacecraft during the moon flights.

5. What is the most important stress of spaceflight to be studied in the Skylab? Describe some of the biomedical experiments. What is the purpose of these experiments?

THINGS TO DO

1 Make a study of the Gemini-7 flight. Describe the experiment conducted on the loss of bone calcium. Tell how Astronauts Borman and Lovell counteracted the effects of weightlessness. Explain the advantages of removing the space suit during flight. This practice was followed on subsequent flights.

2 Make a study of life support during an EVA on the moon. Select one of the Apollo flights during which stay-time on the moon was extended. How did the astronauts get life support during EVA? What were some of the tasks that required large expenditures of energy?

3 Keep a notebook on the Skylab. Were the three visits made? Were space officials able to correct the problems that developed in the Skylab at launch and during the first orbits? How did they do this? Which of the biomedical experiments were carried through as planned? What changes were made?

SUGGESTIONS FOR FURTHER READING

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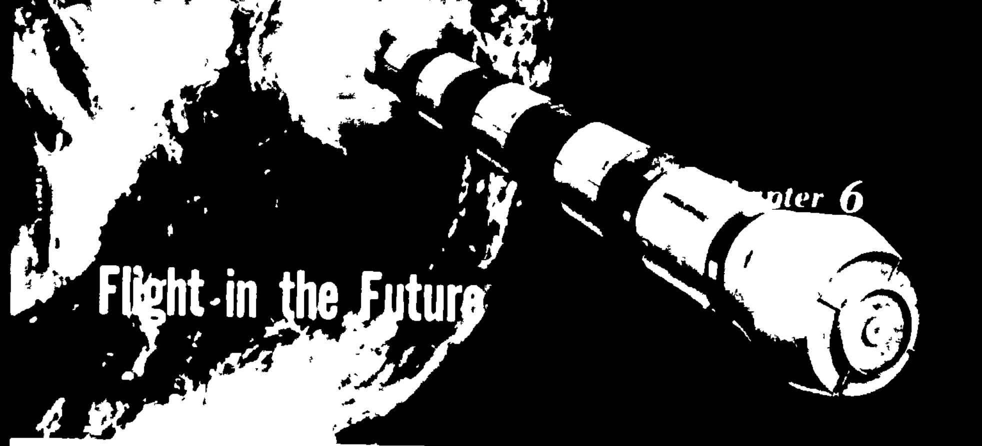

Chapter 6

Flight in the Future

THIS CHAPTER attempts to predict some of the human requirements of aircraft flight and spaceflight in the future. It considers human requirements of two advanced aircraft: the Air Force SR-71 (already in operation) and the commercial supersonic transport. It describes how life support is to be given on the space shuttle and how the space shuttle might be used to develop a space station. Finally, the chapter considers three problems of prolonged spaceflight: the closed life-support system, prevention of contamination, and the mental condition of the passengers and crew. After you have studied this chapter, you should be able to do the following: (1) describe some of the human problems that must be solved when flying future aircraft; (2) name two advancements in life support likely to be made on the space shuttle; (3) explain what is meant by a closed life-support system and tell how it relates to solving pollution problems on the earth; and (4) tell what you think might be the two most serious human problems on prolonged spaceflights.

MAN HAS BEEN FLYING aircraft for only about seventy years and spacecraft for about a dozen years. In this relatively brief time he has learned how to adjust to increasingly severe flight stresses and to keep his body stable during flight. The question that now suggests itself is. How will man continue to counter more severe flight stresses?

ADVANCED AIRCRAFT

In the development of future aircraft, emphasis is being placed upon performance and versatility. To get some idea of the human requirements for flight in future aircraft, consider two advanced aircraft: an Air Force reconnaissance plane (the SR-71, already in operation) and the supersonic transport (SST).

The SR-71 (Fig. 89) cruises at mach 3 (three times the speed of sound) and can reach an altitude higher than 80,000 feet. Because of the great speed at which it travels, aerodynamics heating can cause the skin of the aircraft to heat to temperatures of 500 to 600 degrees F. The aircraft must decelerate and make several turns in a holding pattern to allow the aircraft to cool before making a landing. To descend for a landing, the pilot must begin making his instrument approach many miles away. If the pilot should make a calculation error of even a few seconds at altitude, the aircraft would probably overshoot the approach by many miles. As the SR-71 touches down for a landing, a drag parachute is deployed to help slow down the aircraft. Crew members of the SR-71 wear Gemini-type full pressure suits with heavy footgear. The pilot must use caution in applying the brakes because it is difficult to get the "feel" of the brakes with this footwear.

The SR-71 has a crew of two: the pilot and another officer who acts as both copilot and navigator. The second officer operates the advanced inertial navigation system, which is linked with a star-tracking system.

Two commercial supersonic transports, the Soviet Tu-144 and the British-French Concorde (Fig. 90), cruise at about mach 2 and at altitudes above 50,000 feet. At that altitude, in the lower limits of the space-equivalent zone, a space cabin is needed. Passengers in supersonic transports will be traveling under conditions

Figure 89 Air Force SR-71 The pilot and navigator of this aircraft must have skills and meet flight stresses much like those that will be experienced in aircraft of the future

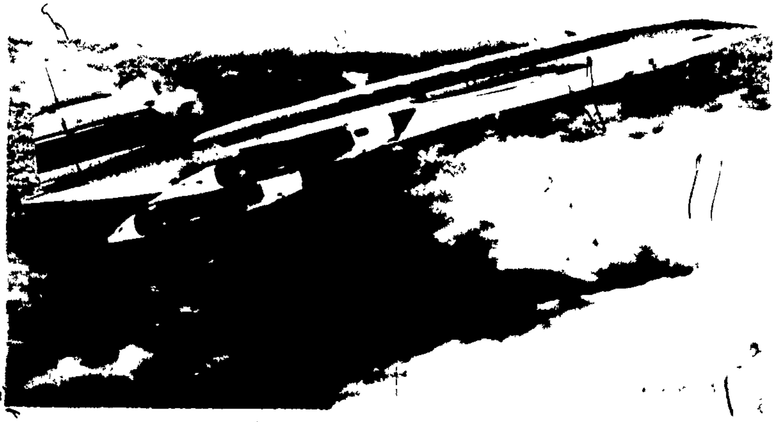

Figure 90 British French Concorde. This is one of the supersonic transports being tested for commercial flight.

much like those under which the astronauts travel. When the Concorde reaches an altitude of 50,000 feet, the space cabin has a pressure altitude of 6,000 feet. The combined heating and air-conditioning system can keep the cabin comfortable.

As supersonic transports reach the speed of sound, they create a sonic boom, but this will not be heard by the passengers, because the shock waves do not travel toward the cabin. To avoid creating sonic booms over population centers, these aircraft are not to be flown at supersonic speeds until they are far out over the oceans.

Flight simulators using advanced avionics (aviation electronics) are being used to assist pilots in transitioning to supersonic transports These simulators realistically reproduce many of the conditions that will be encountered during flight. One condition that is noticeably different between flying a supersonic transport and a subsonic jet is that experienced when making the high-speed takeoff and rapid climb to reach the cruise altitude of 50,000 feet.

Like the SR-71, the Concorde has an inertial navigation system, which permits highly accurate navigation. The aircraft also has autopilots, which can control the aircraft not only during cruising but also during climb and descent.

The high speed of the supersonic transport should greatly reduce passenger fatigue during long-distance flights. Fatigue from flying usually does not become pronounced until 3 to 4 hours after the aircraft is underway. The Concorde can fly from New York to London in about 3 hours 30 minutes.

FUTURE SPACEFLIGHT

While astronauts are conducting experiments in the Skylab, work will continue on the space shuttle and the permanent space station Biomedical specialists and engineers will develop the space cabin and protective equipment needed for the space shuttle, which is to be used for constructing a space station in orbit.

Space Shuttle and Space Station

The first **space shuttle** is to have two stages: an unmanned booster stage and a manned orbiter stage. The shuttle is being designed so that it can be reused for more than 100 flights. The **orbiter stage** of the shuttle (Fig. 91) is to be a delta-winged vehicle about the size of a medium-range jet airliner. It will

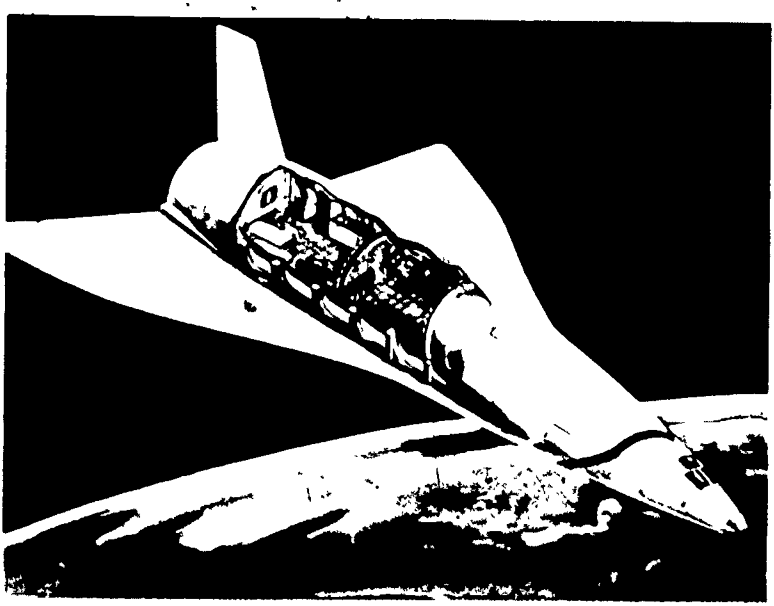

Figure 91. Interior of orbiter stage of the space shuttle. This drawing shows one design for the interior of the shuttle.

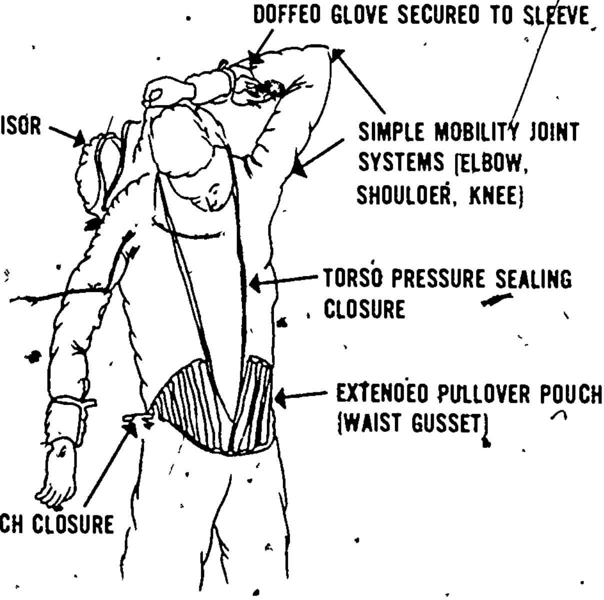

Figure 92. Space suit for pilots of space shuttle. The drawing shows the design of a lightweight suit that could be worn unpressurized for long periods inside the shuttle. The suit could be pressurized quickly in an emergency.

descend from orbit and then fly through the atmosphere like an aircraft.

The orbiter is to carry a four-man crew consisting of a pilot, a copilot, and two special assistants. In addition to the four-man crew, the shuttle could carry as many as 12 passengers, or it could be used entirely for cargo.

When the space shuttle is ready for operation, as it is expected to be in the early 1980s, passengers who travel into orbit will no longer have to receive rigorous training as astronauts. The orbiter stage of the shuttle will have a space cabin, and its maneuvering ability will allow the passengers to enjoy safety and comfort similar to that of the commercial airliner.

Work is now proceeding on a space suit (Fig. 92) for pilots who will test the shuttle. This space suit is intended as a backup for the space cabin. The whole escape system, of which the suit is a part, is being designed to allow the crew to deorbit and land in case of accidental decompression. The suit, made of fabric, is to weigh only about 10 pounds. It will be pressurized at about 5 psi as compared with about 3.5 psi for present space suits. With improvements, pressurization of the new suit to about 8 psi should be possible. Even with the higher pressurization, the suit will provide a high degree of mobility and comfort. The helmet can be folded and stored inside the suit at the neckline. The pressurization in the cabin of the space shuttle will be adjusted to the higher levels in the space suit, and a mixed-gas atmosphere will probably be used in both suit and cabin.

Engineers are also planning a launch escape system for the space shuttle. If trouble should develop in the unmanned booster stage at launch, a rocket engine would propel the orbiter stage away from the booster stage, and the external fuel tank and solid rocket motors of the booster stage would be jettisoned. The orbiter stage would ascend to a high enough altitude to allow it to glide back to the earth.

To assure the safety of the shuttle's passengers and crew during flight, the pilot-astronauts will be provided with advanced biomedical instrumentation. This instrumentation should give doctors on the ground information to enable them to predict medical problems instead of merely recording abnormal functioning as it occurs.

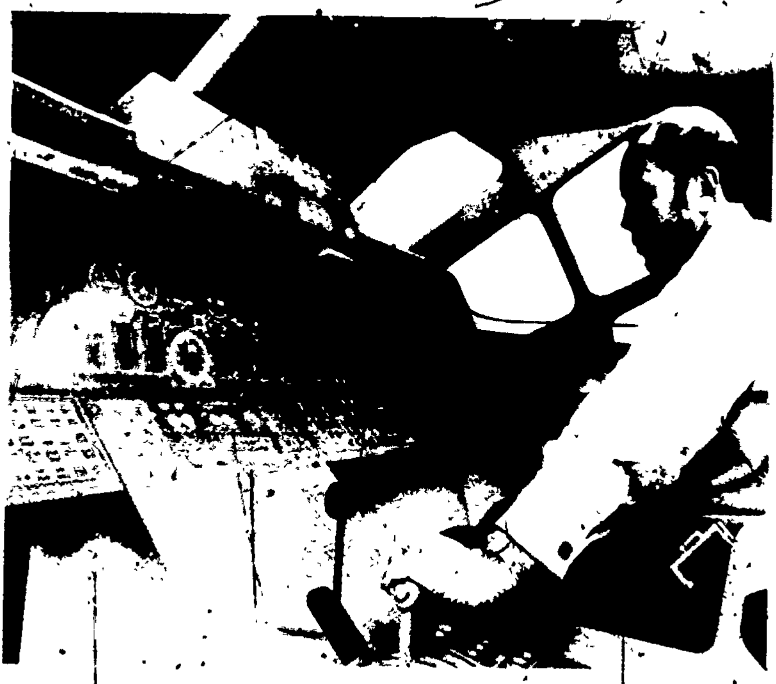

Figure 93 Mockup of crew station in space shuttle showing position of the instrument panel.

Figure 94. Sortie can. The design drawing shows a research module that could be carried into orbit by the space shuttle.

Making the best use of the limited living space will be an important factor in designing the cabin of the space shuttle. Engineers at the Johnson Space Center, near Houston, are preparing mockups of the cabin that provide areas for food storage, waste management, a galley (kitchen), and a work section. A small compartment called a cocoon will allow privacy for each astronaut. The cocoon, which is no longer than a couch, has a built-in radio and tape deck and a small television set. A mockup of the crew station with instrument panels is shown in Figure 93.

Since funds for future space programs have been cut, efforts are being concentrated on the space shuttle. It will probably be used for carrying modules into space to build a space station in orbit.

The first module to be taken into orbit by the shuttle is likely to be the **sortie can** (Fig 94), a relatively simple laboratory. It would be pressurized and have airlocks. A pallet attached to the sortie can would be used for conducting experiments in space.

The first small module would be gradually enlarged into a laboratory called a **research and applications module** (RAM). A number of RAMs might be docked to make up a **modular space station** (Fig. 95).

Prolonged Spaceflight

A US space station might one day be used for preparing astronauts for trips to the planets, especially Mars. With present-day propulsion systems, a flight to and from Mars, with some time allowed for exploration, would take about two years.

Modern technology should be able to solve the problems of human adjustment encountered on a two-year interplanetary voyage. In the days of sailing ships, Europeans were able to circumnavigate the globe in about two years. For such trips enough food and water were stocked for the long overwater stretches.

As soon as space travel passed from the realm of science fiction to that of science, man began to study the possibility of making long space voyages. We might take a look at three areas of study concerning long space voyages, the closed life-support system, contamination in space, and mental qualities needed by men confined in the space ship.

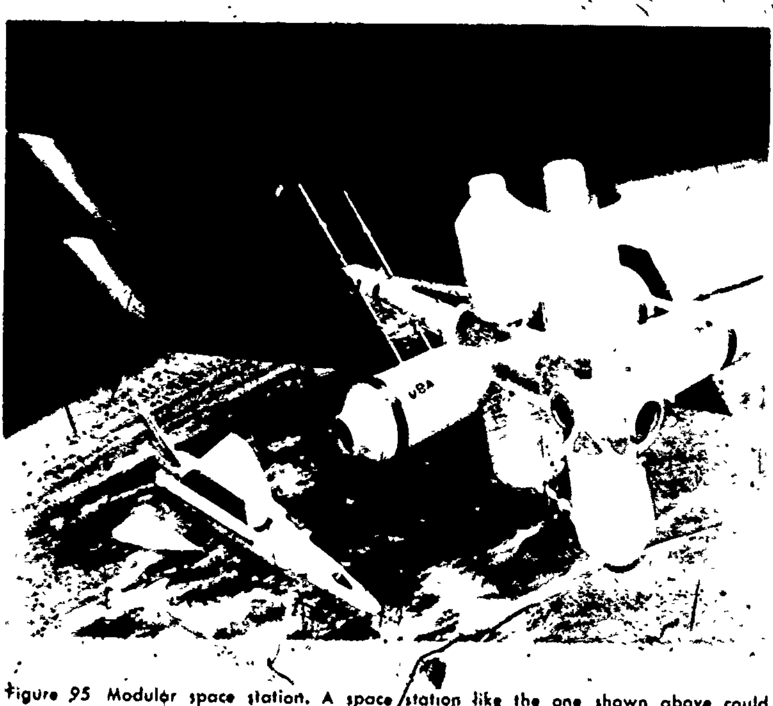

Figure 95 Modular space station. A space station like the one shown above could be assembled piece by piece from modules carried into orbit by the space shuttle

CLOSED LIFE-SUPPORT SYSTEM.—If four astronauts were to store on board all the water, oxygen, and food needed for a two-year trip in space, they would have to carry almost 44 tons of life-support supplies. This rough estimate of 11 tons per astronaut, computed according to figures given in Chapter 4, would make the total weight prohibitive.

The first step in solving the problem would be to reuse the water and oxygen. Scientists and engineers have already begun the process of recycling water and oxygen. NASA scientists are presently working on more advanced water and waste management systems. These would make it possible to recover and reuse water from urine, wash water, and water vapor condensed from the space ship's atmosphere, they would recover water and gases from solid biological wastes, and they would decompose and burn the solid wastes.

Waste management systems being developed for use on future space ships may have direct application for use on the earth. NASA is cooperating with the Department of Housing and Urban Development to see if similar systems could be used by small communities for recycling sewage and thus help to prevent pollution of streams and rivers.

The sum total of all relationships between the organisms and their environment makes up an **ecology**. Space biologists hope to reproduce a complete ecology in miniature, or a **closed life-support system** (Fig. 96), within a space ship. Recycling human wastes into food and water through a waste management system would complete the closed life-support system. To understand how such a system might operate on future space ships, one must go to the world of nature on the earth.

The key to an ecology in nature is found in the balance maintained between living plants and animals. By using the radiant energy of the sun and chlorophyll (green tissue), plants produce a synthesis, or a bringing together, of elements known as **photosynthesis**. Through photosynthesis, plants produce glucose and oxygen from the carbon dioxide exhaled by animals. The animals use the glucose and oxygen from plants for food and breathing, giving off carbon dioxide. Plants again convert the carbon dioxide into glucose and oxygen, and the cycle continues. By making use of photosynthesis, astronauts on future space voyages might obtain food and oxygen from green plants grown on board the space ship.

As early as 1949, when the space department was established at the Air Force School of Aviation Medicine, Dr. Hubertus Strughold began experiments on a closed life-support system for space ships For his first experiments he used *Chlorella* algae and mice. The alga, the plant most often used for experiments to create a closed life-support system, is a simple green plant without true roots, stems, or leaves. Algae vary all the way from the 200-foot-long ocean kelp to simple one-cell algae. The *Chlorella* alga, the one-cell alga found in pond scum, contains enough protein and fat to supply man's daily dietary requirements Unfortunately, *Chlorella* algae do not make an appetizing diet. Higher plant forms, such as mushrooms, corn, and tomatoes, might be introduced both as gas-exchangers and as a means of varying the diet.

NASA scientists at the Ames Research Center, in cooperation with the US Department of Agriculture, are experimenting with a system of water culture and plant nutrients to grow fresh vegetables rapidly under spaceflight conditions.

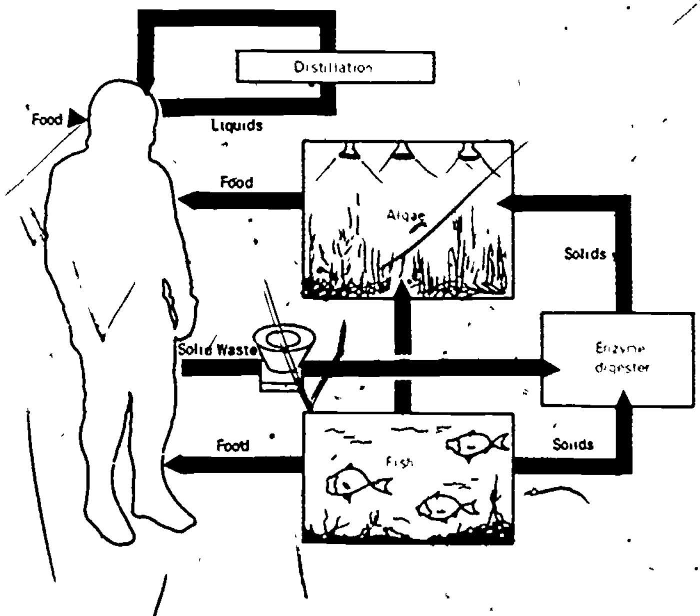

Figure 96. A closed life support system Such a system might be used for prolonged spaceflight in the future

The plants or animals that are to be used in the life cycle in space ships must grow rapidly to produce an abundance of oxygen and food. In nature the source of radiant energy is the sun. In the artificially created environment of a space ship, the sun's radiant energy would be used as much as possible, but it would have to be supplemented with electric power or other energy.

PREVENTION OF CONTAMINATION.—Space scientists and engineers who are looking far into the future are concerned about preventing **contamination,** or the accumulation of dirt and disease-producing organisms in the closed space ship.

Strict precautions are taken to keep present-day spacecraft and space boosters from becoming contaminated All space equipment is handled under **clean-room conditions.** Workers coming into contact with the equipment wear white uniforms like those worn by doctors and nurses (Fig. 97).

Space hardware is kept from contamination for both engineering and health reasons The rocket engines would not operate properly if even small amounts of contaminants got into the propellants or parts of the engine. Further, spacecraft must be kept in a hygienic condition to protect the health of the astronauts. When the spacecraft becomes weightless in orbit, any loose debris or dust would float about in the cabin, creating unsanitary conditions. Within the closed space cabin, astronauts are exposed to contamination from the cabin atmosphere and from each other.

On longer flights into space, astronauts and scientists would be traveling in much larger space vehicles than the Apollo command module and would be able to move about more freely. Long periods of weightlessness would probably cause deconditioning, nevertheless. The astronauts, in their weakened condition, would then become infected more readily as they were exposed to contamination for long periods of time inside the closed space ship. Contamination may well be one of the greatest hazards of prolonged spaceflight.

MENTAL CONDITION OF PASSENGERS AND CREW.—The mental condition of space voyagers in the future will probably be even more important than their physical condition. After two pilots replaced the single astronaut on the Gemini flights, the astronauts found that they had to work closely as a team within the close confines of the spacecraft Although the large space ships of the future will allow more freedom of movement, there will be an even greater need for teamwork. Many men will live and work closely together for as long as two years at a time.

Because scientists are concerned about the reactions of men to each other on long space voyages, they have continued with their

Figure 97 Clean room Astronaut James Lovell is shown entering the clean room on the Apollo mobile launcher at Cape Kennedy. Note the white uniforms the attendants are wearing.

studies of men in close confinement. One of these studies, called Project Tektite, was conducted underwater by the Navy (Fig. 98), and NASA cooperated. In the underwater environment of Project Tektite conditions are similar to those in a space cabin.

During Project Tektite, NASA scientists checked on the mixed nitrogen-oxygen breathing atmosphere, and they obtained data for designing the cabin of the space shuttle. They were also able to judge the reactions of men confined for a period of two months. Contrary to results obtained from previous studies, the crew members in Project Tektite developed no hostilities to each other. Instead, the members of the crew related well to each other during the entire period of confinement. When sources of irritation developed, they got together and talked over their problems, reaching some solution. Sleep patterns gave no clue to tension. The members of the crew slept well and adjusted to their work.

The key to the successful adjustments of the crew members in Project Tektite was found in their high degree of **motivation,** or inspiration to act in order to achieve worthwhile goals.

Astronauts of the future must be men with emotional stability and a high degree of motivation. They must be dedicated to the advancement of spaceflight, whether in astronomy, space biology, aerospace medicine, or some other field. In the future, physical qualifications for scientist-astronauts may be relaxed somewhat but mental qualifications cannot be.

Figure 98 Subjects during Project Tektite. NASA cooperated with the Navy in studying the behavior of persons living underwater for extended periods. The isolation of spaceflight resembles that in an underwater chamber.

TERMS TO REMEMBER

space shuttle
orbiter stage
sortie can
research and applications module (RAM)
modular space station
ecology
closed life-support system
photosynthesis
contamination
clean-room conditions
motivation

QUESTIONS

1. What are some of the human requirements of the SR-71?
2. What are the two supersonic transports? Will they create sonic booms? How can these be handled (if created)? What comforts will the supersonic transports provide for passengers?
3. What are the two parts of the space shuttle? Which part will be manned? How will the shuttle be different from spacecraft flown up to the present time?
4. How can the space shuttle be used for building a space station?
5. What is meant by a closed life-support system? How is it related to an ecology on earth? What basic chemical process in plants makes a closed life-support system possible?
6. Why must special measures be taken to prevent contamination of the space ship during prolonged voyages?
7. What kind of mental stresses might astronauts be subjected to on prolonged spaceflights?
8. In terms of meeting human requirements, do you think a flight to Mars will be possible within the present century? Why or why not?

THINGS TO DO

1 Make a study of one of the military aircraft under development, such as the B-1 bomber Determine the special human requirements in terms of controlling and piloting the aircraft and of providing life support for the pilot.

2 Make a study of the British French Concorde and its human requirements. What special demands does it make of the pilot? Will it be difficult to fly? What measures must be taken to protect passengers at the altitude at which the Concorde cruises? Will the passengers be disturbed by sonic booms?

3 Make a model or diagram of the interior of the orbiter stage of the space shuttle How many crew members is the orbiter to have? If it were to carry only passengers, how many passengers might it accommodate? What plans are being made to provide life support for the shuttle crew?

4. With the help of your biology teacher, try to create a simulated ecology, or closed environment, demonstrating the principles upon which the closed life support system is based. How could you use the product of photosynthesis? What kind of plants would you use for gas exchange? What animals might you use? Write out the plan for your experiment, keeping your objectives in mind.

5. Make a study of contamination on prolonged spaceflights. If astronauts were to take a two-year trip to Mars, what problems of contamination would need to be solved? Why would germs spread easily among the members of the crew? Do you think the crew should include a medical doctor?

SUGGESTIONS FOR FURTHER READING

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