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AEROSPACE MEDICINE

FLIGHT SURGEON'S GUIDE

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Aerospace Medicine

FLIGHT SURGEON'S GUIDE

This pamphlet is a guide and reference for the Air Force Flight Surgeon in the performance of his duties. It combines medical knowledge with engineering and aeronautical facts to provide basic information in the very specialized field of Aerospace Medicine. It also applies to Air Reserve Forces and the Air National Guard. (See summary of revised, deleted, or added material below signature element.)

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Chapter 1

THE AEROSPACE MEDICINE PROGRAM

The science of aerospace medicine has fully recognized the almost insurmountable human problems imposed by modern military aircraft. Aerospace medical research scientists of many disciplines are constantly striving to make it possible for man to adapt to the conditions created by the greater speed, higher altitude, extended range, and increased complexity which characterize the aircraft of today and tomorrow. These scientists have had a large measure of success in the research and development of equipment and procedures that enable the military flier to keep pace with aeronautical and operational developments. The ultimate value of future aeromedical research efforts will be only as great as the degree of successful application of the results of these efforts by the individual Flight Surgeon.

The art and practice of aerospace medicine, therefore, must be vigorously pursued by every Flight Surgeon with the full utilization of all available knowledge. The principal objective of this activity is the continued maintenance of the flier in the highest possible state of effectiveness under all circumstances. To insure that this objective is realized, the scope of the Aerospace Medicine Program includes the application of public health and occupational health measures to the entire military community serving the crew member and his mission. The health of the crew member and his effectiveness in meeting mission objectives are intimately correlated with the health and effectiveness of the entire community. AFM 161-2 prescribes the specific principles and procedures for an effective program. The program can be fulfilled by a conscientious application of general and specific knowledge accumulated in the three main functional areas, namely, flight medicine, military public health, and occupational medicine. The Flight Surgeon is capable of recognizing and solving the problems of the crew member and the community and directs, monitors and supervises various talents toward this objective. The prevention or solution of problems will frequently require the full utilization of all available resources.

The Aerospace Medicine Program is very broadly conceived and involves a multidisciplined application of effort by many talented professionals. While flight surgeons direct the program, the efforts of clinical specialists, veterinarians, bioenvironmental engineers, aeromedical and preventive medicine technicians and supervisors, and other members of the Medical Service are indispensable in the conduct of the total program. It is exceedingly important to recognize the requirements for the varied skills and equipment available and to encourage and direct this support capability.

The Flight Medicine Program is specifically dedicated to the anticipation and recognition of the problems of the crew member and the proper use of available means to prevent or solve these problems. In the interest of emphasizing the multiplicity and complexity of problems that occur, it is worth mentioning a few broad categories of problems related to the crew member and aerospace crew effectiveness, and briefly indicate available means for their solution.

The physical and psychological selection of aerospace crew members remains one of the primary missions of aerospace medicine. This activity has become more critical with the advent of supersonic jet flight and manned space operations. The Flight Surgeon's contribution to selection is crucial and depends upon the accurate and expert accomplishment of prescribed examining procedures in the application of the medical standards for flying. The procedures for medical examination are not included in the Flight Surgeon's Guide, since they are in AFM 160-1. That manual includes all medical standards, physical profile serial, and examining techniques for convenience of frequent correlative reference.

The problems related to flight-induced abnormalities and medical conditions, which may affect ability to fly, will require the application of the finest diagnostic abilities and the best of medical judgment. The condition may be acutely or chronically induced by the stress of flying or it may have some other cause. In any event, it must be diagnosed, properly treated, and thoroughly evaluated with respect to the individual's flying status. In the management of such cases, the Flight Surgeon maintains adequate administrative control of the flier to prevent untoward happenings which may occur when the unfit fly. Good medical care, personal observation, and proper performance of periodic medical examinations alleviate the many problems arising in this category.

The most critical problems are encountered in the area concerned with the protection of the flier against the hazards and stresses of flight. The complexity of these problems is readily recognized when one considers the many hazards and stresses encountered by the aircrews of modern operational aircraft. The hazards imposed by high altitude include hypoxia, decompression sickness, temperature extremes, cosmic radiation, and visual disturbances. The very high speeds produce stress through the application of accelerative forces—linear, angular, and radial—and by the production of extremely high temperatures. High speed also poses certain important visual limitations.

The occasional necessity for the flier to abandon his aircraft in flight presents many problems of escape compounding the problems of both high speed and high altitude. Inevitable crash landings and ditchings make it necessary to consider the problems of crash decelerative forces and the protection of the individual against these forces. In addition, medical problems are associated with survival and rescue under almost any circumstances and in every part of the world.

Many special stresses also may plague the flier. Some of these are: exposure to toxic substances, including those associated with aircraft operation and unconventional warfare; vibration, sound, ultrasound; the hazards of many types of projectiles; fire hazards, and circumstances that induce the sensory illusions of flight. The solution to many of these problems may be found in training in the use of survival and personal equipment, physiological training, and the medical indoctrination of aircrews. The Flight Surgeon is the key figure in the success of these important activities.

Another category of problems concerns those resulting from effects of prolonged physical, physiological, and psychological stresses. These problems may be considered to fall into three distinct groups. The first is that of *mission fatigue*, which is produced by prolonged application on a single mission and results in a temporary performance decrement that can be relieved rapidly by adequate rest. The second group is commonly termed *flying fatigue*, which amounts to a loss of keenness for flying or staleness induced by the cumulative effects of too much flying within a given period of time, often coupled with nonspecific everyday life stresses. This is usually reversible by a moderately extended period of rest. The last group consists of conditions referred to as *combat* or *operational fatigue*, which occurs in fliers as a consequence of exposure to the stress of combat flying. In general, this involves stresses such as heavy flying commitments, less than ideal living conditions, family separations, interrupted and changing schedules, and other problems that may compound to compromise skilled performance. All of these conditions require close observation, supervision, and special care by the Flight Surgeon. In no other problem area is there a greater requirement for diligent and close personal observation of the flier.

The maintenance of a high level of physical fitness among all fliers may become, at times, a special problem for the Flight Surgeon. Certainly, the support given by the Flight Surgeon in the physical fitness program can be of immeasurable benefit to the effectiveness of the organization.

Nutritional problems arise frequently. Of particular interest to the Flight Surgeon are the difficulties encountered in affording adequate in-flight feeding for aircrew members. The Flight Surgeon must be concerned with both the sanitation aspects of food service and the many deterrents to adequate nutrition imposed by the in-flight situation. Usually, these problems can be solved through the effective teamwork of the Flight Surgeon and the food service personnel.

The medical aspects of flying safety present many important requirements. Problems of emergency crash procedures and casualty management must be met by proper planning and training. The investigation of aircraft accidents is a first consideration in the flight safety research program. The Flight Surgeon's part of the investigation often predominates because of the high incidence of human factors that cause accidents. The flying safety program of every activity should have the support of the Flight Surgeon.

Certain problems regarding the aircraft and its equipment are of concern to the Flight Surgeon in the interest of combat effectiveness. To recognize and evaluate these problems, the Flight Surgeon observes the flier closely in his crew position. Further, the Flight Surgeon considers any aspect of aircraft or equipment design that affects safety, comfort, well-being, and efficiency. This is particularly true from the standpoint of psychological, physiological, and anatomical considerations. In studying these problems, solutions or "fixes" may become apparent to the Flight Surgeon. To generate action, he may use the medium of the "Unsatisfactory Report." Similarly, he may report to the proper research agencies special observations which, ultimately, may result in important developments.

These various categories of problems of the crewmember and the recognition and application of the methods for their prevention or solution typify the Flight Medicine Program approach to aerospacecrew effectiveness. This program represents the major role of the Flight Surgeon in his support of the operational mission. Much of the specific knowledge essential to the accomplishment of such a program will be found in the pages that follow.

The Military Public Health and Occupational Medicine Programs which constitute the two other major functional parts of the Aerospace Medicine Program are discussed in a subsequent chapter.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Aerospace Medicine*, Chapter 26, Aircrew Maintenance, The Williams and Wilkins Co., Baltimore (1961).

McFarland, R. A., *Human Factors in Air Transportation*, McGraw-Hill Book Co., Inc., New York (1953).

AFM 161-2, *Conducting the Aerospace Medicine Program*.

Chapter 2

EFFECTS OF DECREASED PARTIAL PRESSURE OF OXYGEN ON RESPIRATORY PHYSIOLOGY

It is recognized generally that the most serious, single danger for the flier is the decreased partial pressure of oxygen encountered at low barometric pressures which, without the proper use of oxygen equipment and cabin pressurization, can quickly lead to incapacitation or even death, depending on the flight altitude. This type of hypoxia (insufficient oxygen in the inspired air) ranges from moderate to severe, to fulminating at altitudes between 10,000 and 35,000 feet and higher. At least 75 hypoxic fatalities occurred in the European Theater during World War II at altitudes between 17,000 and 31,000 feet. In these cases, the duration of the hypoxic exposure prior to death varied between less than 3 minutes (five cases) to more than an hour, with 27 fatalities reportedly occurring within 10 minutes or less, as estimated by fellow crewmembers. Two deaths occurred at altitudes between 17,000 and 20,000 feet, a fact which emphasizes that, under no conditions can the lethal effects of acute altitude hypoxia be underestimated, particularly in view of the current routine flight altitudes above 40,000 feet for commercial and military aircraft and manned space flights.

Man's tolerance to hypoxia has not changed since World War II, but the altitude capability of high performance aircraft and the requirement for adequate protective equipment and strict oxygen discipline have all continued to increase in importance and significance. Even hypoxic episodes that lead only to mental confusion or unconsciousness, but not necessarily death, may result ultimately in the total loss of the aircraft, crew, and passengers, because of the mental disorientation during and following the episode and the consequences stemming from uncontrolled aircraft at possibly supersonic speeds.

To understand and appreciate the nature of altitude hypoxia requires primarily an understanding of the physiology of respiration under both normal and abnormal environmental conditions.

The chief purpose of the respiratory process is to supply the lungs and, consequently, the blood and tissues with adequate oxygen and to eliminate the carbon dioxide that is generated by the metabolism of the body tissues—thus a homeostatic state is maintained in spite of a wide variety of conditions and activities. The respiratory process, in conjunction with the renal system, also plays a role in maintaining the acid-base balance of the body within narrow limits under normal environmental conditions, however, in chronic hypoxic environments, the kidney is the major factor in this regard and is important in the process of altitude acclimatization.

Respiration may be divided into three general categories—namely, the pulmonary phase, the blood transport phase, and the tissue phase. The pulmonary phase involves the exchange of gases between the external or ambient atmosphere and the alveolar air, and between the alveolar air and the blood in the pulmonary capillaries. The transport phase depends on an adequate cardiovascular system and blood constituents for transporting the respiratory gases in adequate quantities between the lungs and tissues. The tissue phase of respiration involves the exchange of gases between the cells of the body and the blood in the tissue capillaries.

Pulmonary Phase of Respiration

The total volume of air in the lungs (total lung capacity) is subdivided as shown in figure 2-1. These subdivisions are important in the study of pulmonary function in health, in disease, and under abnormal environmental conditions, such as pressure breathing. The end of a quiet expiration is the usual reference point when making quantitative measurements of these subdivisions.

At the end of quiet expiration, the elastic recoil force of the lung is approximately balanced by the expansile tendency of the chest wall. It, therefore, is often called the equilibrium point. There are four primary lung volumes, as shown in the related illustration. Combinations of two or more primary lung volumes are known as lung capacities. These sometimes reflect the functional compartments of the lung more accurately, than do the lung volumes.

The definitions and average normal values (measured in the resting state, BTPS (gas volume in the lung existing at *B*ody *T*emperature and atmospheric *P*ressure and completely *S*aturated with water vapor at body temperature)) for the primary lung volumes are as follows:

a. *Tidal volume* is the volume of air exchanged in one breath. The resting tidal volume is about 500 cc.

b. *Inspiratory reserve volume* is rarely referred to since it is quite variable, depending on the amount of the tidal volume. It is the maximum amount of air that can be inspired at the end of a resting inspiration.

c. *Expiratory reserve volume* is the maximum amount of air that can be forcibly expired following a normal expiration. The average value is about 1200 cc.

d. *Residual volume* is the amount of air

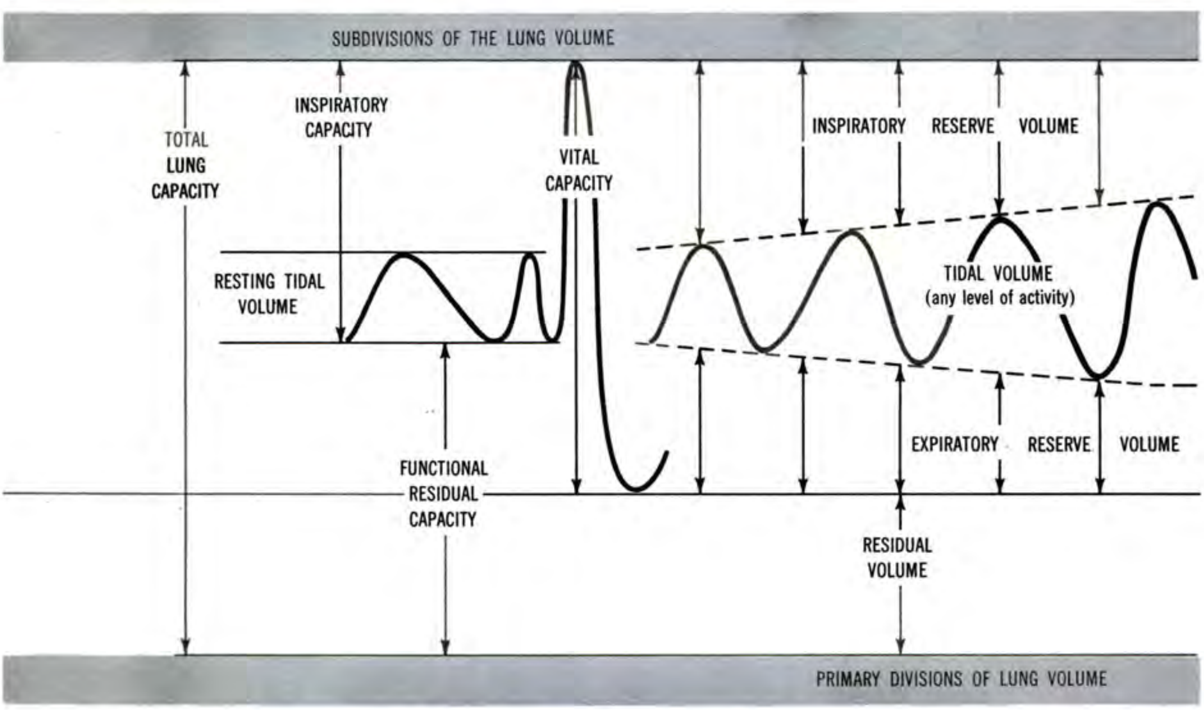


Figure 2-1. Standardization of Terms Used in Respiratory Physiology.

remaining in the lungs following a maximum expiratory effort. The average value is about 1200 cc, and constitutes 20 to 25% of the total lung capacity.

There are also four major lung capacities:

(1) *Total lung capacity* is the sum of all four of the primary lung volumes and averages about 6000 cc.

(2) *Inspiratory capacity* is the maximum volume of air that can be inhaled from the end of a quiet expiration (the sum of the tidal volume and inspiratory reserve volume). The average value is about 3600 cc.

(3) *Vital capacity* is the maximum amount of air that can be exhaled from the lungs following a maximum inspiration. The average value is about 4800 cc. It is the sum of the inspiratory reserve volume, tidal volume, and expiratory reserve volume.

(4) *Functional residual capacity* is the amount of air remaining in the lungs following a normal tidal expiration.

Measurements of all lung volumes and capacities can be made with a spirometer or similar calibrated recording device. The values given for the lung volumes and capacities are approximations only. The values are affected by the age, sex, height, and weight of the subject, and more accurate values may be calculated for individual subjects by using regression formulas which take these variables into account. When regression formulas are used to predict the normal values, the results are often given as "percent of predicted normal."

Knowledge of pulmonary physiology has increased rapidly in recent years. A significant number of advances have resulted from research associated with aviation physiology. A brief summary of some important concepts follows:

The major physiologic functions of the lungs can be grouped under three main headings, namely, *ventilation, diffusion,* and *perfusion.*

(a) *Ventilation* may be defined as the mass movement of air in and out of the lungs or the process by which alveolar air is periodically mixed with atmospheric air. Adequate ventilation is dependent upon the creation of a pressure gradient between the alveoli and the external atmosphere by the bellows action of the chest and diaphragm acting upon the lung. The patency of the airways, the integrity of the "respiratory center" in the medulla, the strength of the intercostal and abdominal muscles and the diaphragm, and the elastic characteristics of the lung and thorax systems are important factors in the maintenance of adequate ventilation. In addition, distribution of the inspired gases throughout the lung is of great importance.

The presence of bronchial secretions, bronchiolar narrowing, or masses occluding some of the airways will cause the alveoli to be unevenly ventilated. Some will be normally ventilated or hyperventilated, and others will be underventilated. Uneven distribution of inspired air may cause the lung to function as a group of compartments, each ventilating at its own rate. For example, about 50% of normal people show relatively slow ventilation of a lung compartment equalling 10 to 50% of the functional residual capacity. In individuals with severe obstructive emphysema, as much as two-thirds of the functional residual capacity may receive only 10% of the total ventilation.

(b) *Diffusion* of gases across the alveolar-capillary wall refers to the mechanism by which the respiratory gases are transferred from the alveolar air to the blood in the pulmonary capillaries and vice versa. Carbon dioxide diffuses across the alveolar wall about 20 times as rapidly as oxygen. However, the pressure gradient of oxygen across the alveolar membrane is normally about 10 times as great as the pressure gradient of CO_2. The presence of fibrosis, granuloma, edema, or exudate in the alveoli or in the alveolar-capillary wall interferes markedly with the process of diffusion and may result in hypoxia or CO_2 retention, or both. Certain types of diffusion abnormalities, such as granulomatous involvement of the alveolar wall in pulmonary sarcoidosis, are referred to as "alveolar-capillary block syndromes."

In diseases leading to abnormalities of diffusion, oxygen diffusion is generally impaired earlier and to a greater degree than is CO_2 diffusion. This is due chiefly to the much greater diffusibility of CO_2 across the alveolar-capillary membrane. Thus, by means of increasing the minute volume of ventilation, normally functioning areas of lung may compensate for CO_2 retention in diseased areas. On the other hand, for end-capillary blood in the pulmonary circulation to become adequately saturated with oxygen, the oxygen must diffuse across the alveolar membrane, through the interstitial fluid and the capillary endothelium. Within the capillary, the dissolved oxygen must then diffuse through the plasma, the red blood cell membrane, and the intracellular fluid within the red cell to combine with the hemoglobin. Thus, oxygen must diffuse from a gaseous state in the alveoli to a dissolved state within the alveolar membrane and the pulmonary-capillary tissues and fluids. The solubility of a gas, as well as its partial pressure, greatly influences its diffusion characteristics. Carbon dioxide is about 25 times more soluble than oxygen in pulmonary tissues and fluids and, as indicated above, its capacity for diffusion is about 20 times greater than oxygen.

Figure 2–2 compares the different rates of oxygen uptake by the blood when breathing low and high levels of oxygen. The average time for the passage of blood through the lung capillaries for the exchange of respiratory gases has been estimated by Roughton to be about 0.75 second when at rest, and about 0.33 second or faster during heavy exercise. (For a detailed and quantitative discussion of the respiratory functions of the blood, refer to chapter 5 (Roughton), *Handbook of Respiratory Physiology,* listed under References at the end of this chapter.)

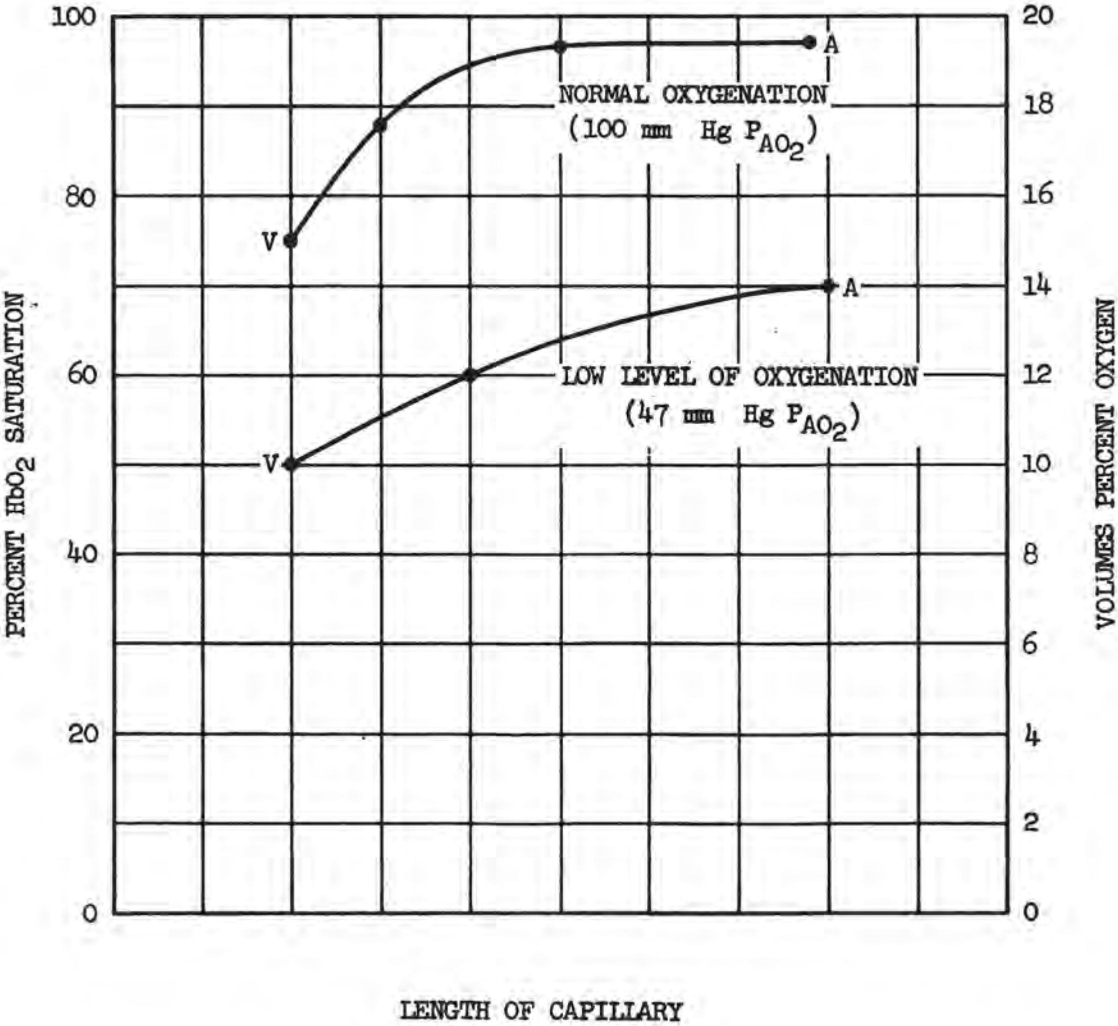
(c) *Perfusion* of blood through the lung capillaries is not always uniform, even in normal individuals. In various disease states, blood flow through the lung may vary greatly from one area to another. Uneven perfusion of the lungs with blood may become a very serious matter when combined with uneven ventilation of the lung. Some areas of lung may be well-ventilated but poorly perfused. These areas merely increase the dead space and do not contribute to gas exchange. Other areas may be well-perfused but poorly ventilated. These areas act virtually as right-to-left vascular shunts since the blood flowing through them retains its venous character.

Disturbances of ventilation-perfusion relationships may occur during flight when "G" forces act on the lung during acceleration, causing redistribution of the blood flow to the lungs. *For example,* during exposure to footward "G" forces, the lower lobes would become somewhat engorged. During exposure to headward G forces, the apical regions would become engorged. Other ventilation-perfusion disturbances can result from pressure breathing and from such dysbaric syndromes as the "chokes" or any abnormal alterations in the pulmonary circulation.

Composition of Respired Air

Dry atmospheric air contains 20.95% oxygen, 79.02% nitrogen, and 0.03% carbon dioxide by volume. Included with the nitrogen are small amounts of rare gases that apparently have no physiological significance. The relative percentage composition of dry atmospheric air does not vary appreciably with altitudes up to 80,000 feet or about 15 miles. Above these altitudes, the percentage of oxygen very gradually decreases and the percentage of the trace gas helium increases slightly because of their molecular weights and the influence of gravity. There are no significant variations with latitude (see table 2–1).

Quantities of gas at various altitudes expressed in percentages of the atmosphere have little significance, for percentage represents the relative volume of a gas and not its molecular concentration. Since molecular concentration determines the availability of the gas to the body, the actual concentration of any gas is best expressed in terms of "partial pressure."



PERCENT HbO_2 SATURATION	VOLUMES PER-CENT OXYGEN
LOW LEVEL	
1. 50	10
2. 60	12
3. 70	14
NORMAL LEVEL	
1. 75	15
2. 88	17.6
3. 96	19.2
4. 97	19.4

Changes in percent oxygen saturation as blood passes along a lung capillary under conditions of normal alveolar oxygen tension (100 mm Hg) and alveolar hypoxia (47 mm Hg). A=Arterial; V=Mixed venous blood.

Figure 2-2. Blood Oxygen Saturation Values in a Lung Capillary.

The partial pressure of a gas, in a mixture of gases not interacting with one another, is equal to that pressure which the particular gas would exert if it alone occupied the space taken up by the mixture (Dalton's Law). The "total pressure" of a mixture of gases is, therefore, the sum of the pressures of the individual gases composing the mixture. For moist air, this law can be represented by the formula:

$$P_B = P_{O_2} + P_{N_2} + P_{CO_2} + P_{H_2O}$$

where P_B is the total barometric pressure, and P_{O_2}, P_{N_2}, P_{CO_2}, and P_{H_2O} are the partial pressures of oxygen, nitrogen, carbon dioxide, and water vapor, respectively.

The total standard pressure (barometric pressure) of the atmosphere at sea level is 760 mm Hg (14.7 psi). When the air is assumed to be dry, the partial pressure exerted by oxygen at sea level is:

TABLE 2-1. CHEMICAL COMPOSITION OF THE ATMOSPHERE (DRY) AT SEA LEVEL.

Constituent	*Molecular Weight*	*Percent by Volume*
Nitrogen (N_2)	28.016	78.09
Oxygen (O_2)	32.000	20.95
Argon (A)	39.944	0.93
Carbon dioxide (CO_2)	44.010	0.03
Neon (Ne)	20.183	1.8×10^{-3}
Helium (He)	4.003	5.24×10^{-4}
Krypton (Kr)	83.7	1.0×10^{-4}
Hydrogen (H_2)	2.016	5.0×10^{-5}
Xenon (Xe)	131.3	8.0×10^{-6}
Radon (Rn)	222.	6.0×10^{-18}
Dry Air	28.966	100.00

$$\frac{20.95}{100} \times 760 = 159 \text{ mmHg (3.1 psi)}.$$

The partial pressure exerted by nitrogen at sea level is:

$$\frac{79.02}{100} \times 760 = 601 \text{ mmHg (11.6 psi)}.$$

The partial pressures of the other gases may be similarly calculated.

Table 2-2 summarizes the barometric pressure of the atmosphere at various altitudes.

Composition of Pulmonary Air

The atmospheric air that is drawn through the nasal passages into the trachea becomes saturated with water vapor. Furthermore, it mixes with the alveolar air. One must visualize in the alveoli, an interface across which gaseous interchange occurs between the air previously present in the alveoli and that which has newly entered. The newly entered air "delivers" oxygen and "receives" carbon dioxide, whereas that already present in the alveoli "receives" oxygen and "yields" carbon dioxide. Therefore, expired air contains less oxygen and more carbon dioxide than does inspired air which normally is essentially free of carbon dioxide. Expired air does not give a true picture of the conditions that exist in the alveoli, since it is a mixture of air from the alveoli and from the dead space. The partial pressure of oxygen in the alveoli determines how much oxygen reaches the blood and tissues. The partial pressures of the gases in the alveoli at sea level and at various altitudes when breathing air and when breathing 100% oxygen are shown in table 2-3, which provides a comparison of the equivalent altitudes at which the alveolar gas compositions are essentially the same.

When man is breathing pure oxygen at 33,700 feet, the partial pressure of oxygen in the alveoli is the same as the pressure at sea level when breathing air. Above 34,000 feet, the partial pressure of oxygen in the lungs begins to fall below the pressure at sea level, even though 100% oxygen is breathed. At altitudes greater than 40,000 feet, the partial pressure of oxygen decreases rapidly

TABLE 2-2. BAROMETRIC PRESSURE AND TEMPERATURE CHANGES WITH THE GEOMETRIC ALTITUDE.

US Standard Atmosphere (1962) (1 torr = 1 mm Hg)

	Pressure			Temperature	
Alt (Feet)	Torr	in.Hg	PSIA	°F.	°C.
Sea Level	760.00	29.92	14.70	59.0	15.0
500	746.37	29.38	14.43	57.2	14.0
1000	732.93	28.86	14.17	55.4	13.0
1500	719.70	28.33	13.92	53.7	12.0
2000	706.66	27.82	13.66	51.9	11.0
2500	693.81	27.32	13.42	50.1	10.0
3000	681.15	26.82	13.17	48.3	9.1
3500	668.69	26.33	12.93	46.5	8.1
4000	656.40	25.84	12.69	44.7	7.1
4500	644.30	25.37	12.46	43.0	6.1
5000	632.38	24.90	12.23	41.2	5.1
5500	620.65	24.43	12.00	39.4	4.1
6000	609.09	23.98	11.78	37.6	3.1
6500	597.70	23.53	11.56	35.8	2.1
7000	586.49	23.09	11.34	34.0	1.1
7500	575.45	22.66	11.13	32.3	0.1
8000	564.58	22.23	10.92	30.5	−0.8
8500	553.88	21.81	10.71	28.7	−1.8
9000	543.34	21.39	10.51	26.9	−2.8
9500	532.97	20.98	10.31	25.1	−3.8
10000	522.75	20.58	10.11	23.4	−4.8
10500	512.70	20.19	9.91	21.6	−5.8
11000	502.80	19.80	9.72	19.8	−6.8
11500	493.06	19.41	9.53	18.0	−7.8
12000	483.48	19.03	9.35	16.2	−8.8
12500	474.04	18.66	9.17	14.5	−9.8
13000	464.76	18.30	8.99	12.7	−10.7
13500	455.62	17.94	8.81	10.9	−11.7
14000	446.63	17.58	8.64	9.1	−12.7
14500	437.79	17.24	8.47	7.3	−13.7
15000	429.08	16.89	8.30	5.5	−14.7
15500	420.52	16.56	8.13	3.8	−15.7
16000	412.10	16.22	7.97	2.0	−16.7
16500	403.82	15.90	7.81	0.2	−17.7
17000	395.67	15.58	7.65	−1.6	−18.7
17500	387.65	15.26	7.50	−3.4	−19.6
18000	379.77	14.95	7.34	−5.1	−20.6
18500	372.02	14.65	7.19	−6.9	−21.6
19000	364.40	14.35	7.05	−8.7	−22.6
19500	356.90	14.05	6.90	−10.5	−23.6
20000	349.53	13.76	6.76	−12.3	−24.6
20500	342.29	13.48	6.62	−14.0	−25.6
21000	335.17	13.20	6.48	−15.8	−26.6
21500	328.16	12.92	6.35	−17.6	−27.6
22000	321.28	12.65	6.21	−19.4	−28.5
22500	314.51	12.38	6.08	−21.2	−29.5
23000	307.86	12.12	5.95	−22.9	−30.5
23500	301.33	11.86	5.83	−24.7	−31.5
24000	294.91	11.61	5.70	−26.5	−32.5
24500	288.60	11.36	5.58	−28.3	−33.5
25000	282.40	11.12	5.46	−30.0	−34.5
25500	276.31	10.88	5.34	−31.8	−35.5
26000	270.32	10.64	5.23	−33.6	−36.4

TABLE 2-2. Continued.

	Pressure			Temperature	
Alt (Feet)	*Torr*	*in.Hg*	*PSIA*	*°F.*	*°C.*
26500	264.44	10.41	5.11	−35.4	−37.4
27000	258.67	10.18	5.00	−37.2	−38.4
27500	253.00	9.96	4.89	−38.9	−39.4
28000	247.43	9.74	4.78	−40.7	−40.4
28500	241.96	9.53	4.68	−42.5	−41.4
29000	236.59	9.31	4.57	−44.3	−42.4
29500	231.31	9.11	4.47	−46.1	−43.4
30000	226.13	8.90	4.37	−47.8	−44.4
30500	221.05	8.70	4.27	−49.6	−45.3
31000	216.06	8.51	4.18	−51.4	−46.3
31500	211.16	8.31	4.08	−53.2	−47.3
32000	206.35	8.12	3.99	−54.9	−48.3
32500	201.63	7.94	3.90	−56.7	−49.3
33000	197.00	7.76	3.81	−58.5	−50.3
33500	192.46	7.58	3.72	−60.3	−51.3
34000	188.00	7.40	3.64	−62.1	−52.3
34500	183.62	7.23	3.55	−63.8	−53.2
35000	179.33	7.06	3.47	−65.6	−54.2
36000	170.99	6.73	3.31	−69.2	−56.2
37000	163.00	6.42	3.15	−69.7	−56.5
38000	155.37	6.12	3.00	−69.7	−56.5
39000	148.11	5.83	2.86	−69.7	−56.5
40000	141.18	5.56	2.73	−69.7	−56.5
41000	134.58	5.30	2.60	−69.7	−56.5
42000	128.29	5.05	2.48	−69.7	−56.5
43000	122.30	4.81	2.36	−69.7	−56.5
44000	116.58	4.59	2.25	−69.7	−56.5
45000	111.13	4.38	2.15	−69.7	−56.5
46000	105.94	4.17	2.05	−69.7	−56.5
47000	100.99	3.98	1.95	−69.7	−56.5
48000	96.27	3.79	1.86	−69.7	−56.5
49000	91.77	3.61	1.77	−69.7	−56.5
50000	87.49	3.44	1.69	−69.7	−56.5
51000	83.40	3.28	1.61	−69.7	−56.5
52000	79.51	3.13	1.54	−69.7	−56.5
53000	75.79	2.98	1.47	−69.7	−56.5
54000	72.25	2.84	1.40	−69.7	−56.5
55000	68.88	2.71	1.33	−69.7	−56.5
56000	65.67	2.59	1.27	−69.7	−56.5
57000	62.60	2.46	1.21	−69.7	−56.5
58000	59.68	2.35	1.15	−69.7	−56.5
59000	56.89	2.24	1.10	−69.7	−56.5
60000	54.24	2.14	1.05	−69.7	−56.5
61000	51.71	2.04	1.00	−69.7	−56.5
62000	49.30	1.94	9.53^{-1}	−69.7	−56.5
63000	47.00	1.85	9.09	−69.7	−56.5
64000	44.80	1.76	8.66	−69.7	−56.5
65000	42.71	1.68	8.26	−69.7	−56.5
66000	40.72	1.60	7.87	−69.6	−56.4
67000	38.82	1.53	7.51	−69.1	−56.1
68000	37.02	1.46	7.16	−68.5	−55.8
69000	35.30	1.39	6.83	−68.0	−55.5
70000	33.66	1.33	6.51	−67.4	−55.2
71000	32.10	1.26	6.21	−66.9	−54.9

TABLE 2-2. Continued.

	Pressure			Temperature	
Alt (Feet)	*Torr*	*in.Hg*	*PSIA*	*°F.*	*°C.*
72000	30.62	1.21	5.92	−66.3	−54.6
73000	29.20	1.15	5.65^{-1}	−65.8	−54.3
74000	27.86	1.10	5.39	−65.2	−54.0
75000	26.57	1.05	5.14	−64.7	−53.7
76000	25.35	9.98^{-1}	4.90	−64.2	−53.4
77000	24.19	9.52	4.68	−63.6	−53.1
78000	23.08	9.09	4.46	−63.1	−52.8
79000	22.02	8.67	4.26	−62.5	−52.5
80000	21.01	8.27	4.06	−62.0	−52.2
81000	20.05	7.90	3.88	−61.4	−51.9
82000	19.14	7.54	3.70	−60.9	−51.6
83000	18.27	7.19	3.53	−60.3	−51.3
84000	17.44	6.87	3.37	−59.8	−51.0
85000	16.65	6.55	3.22	−59.3	−50.7
86000	15.89	6.26	3.07	−58.7	−50.4
87000	15.17	5.97	2.93	−58.2	−50.1
88000	14.49	5.70	2.80	−57.6	−49.8
89000	13.83	5.45	2.67	−57.1	−49.5
90000	13.21	5.20	2.55	−56.5	−49.2
91000	12.61	4.97	2.44	−56.0	−48.9
92000	12.05	4.74	2.33	−55.4	−48.6
93000	11.51	4.53	2.22	−54.9	−48.3
94000	10.99	4.33	2.13	−54.4	−48.0
95000	10.50	4.13	2.03	−53.8	−47.7
96000	10.03	3.95	1.94	−53.3	−47.4
97000	9.58	3.77	1.85	−52.7	−47.1
98000	9.15	3.60	1.77	−52.2	−46.8
99000	8.75	3.44	1.69	−51.6	−46.5
100000	8.36	3.29^{-1}	1.62^{-1}	−51.1	−46.2
101000	7.99	3.14	1.54	−50.6	−45.9
102000	7.63	3.01	1.48	−50.0	−45.6
103000	7.29	2.87	1.41	−49.5	−45.3
104000	6.97	2.75	1.35	−48.9	−45.0
105000	6.66	2.62	1.29	−48.4	−44.7
106000	6.37	2.51	1.23	−47.4	−44.1
107000	6.09	2.40	1.18	−45.8	−43.2
108000	5.82	2.29	1.13	−44.3	−42.4
109000	5.57	2.19	1.08	−42.8	−41.6
110000	5.33	2.10	1.03	−41.3	−40.7
120000	3.45	1.36	6.67^{-2}	−26.1	−32.3
130000	2.27	8.92^{-2}	4.38	−10.9	−23.8
140000	1.51	5.95	2.92	+4.3	−15.4
150000	1.02	4.02	1.97	+19.4	−7.0
160000	6.97^{-1}	2.75	1.35	+27.5	−2.5
170000	4.78	1.88	9.23^{-3}	+27.5	−2.5
180000	3.26	1.28	6.31	+18.9	−7.3
190000	2.21	8.70^{-3}	4.27	+8.1	−13.3
200000	1.48	5.85	2.87	−2.7	−19.3
210000	9.85^{-2}	3.88	1.91	−22.0	−30.0
220000	6.41	2.52	1.24	−43.5	−41.9
230000	4.08	1.60	7.88^{-4}	−64.9	−53.9
240000	2.53	9.95^{-4}	4.89	−86.4	−65.8
250000	1.53	6.01	2.95	−107.8	−77.7
260000	8.92^{-3}	3.51	1.73	−129.3	−89.6

TABLE 2-2. Continued.

	Pressure			*Temperature*	
Alt (Feet)	*Torr*	*in.Hg*	*PSIA*	*°F.*	*°C.*
270000	5.09	2.00	9.85^{-5}	−134.5	−92.5
280000	2.90^{-3}	1.14^{-4}	5.62^{-5}	−134.5	−92.5
290000	1.66	6.52^{-5}	3.20	−134.5	−92.5
300000	9.49^{-4}	3.74	1.84	−126.8	−88.2
350000	8.52^{-5}	3.35^{-6}	1.65^{-6}	−24.5	−31.4
400000	1.60	6.30^{-7}	3.10^{-7}	233.9	112.2
450000	6.31^{-6}	2.48	1.22	734.1	390.1
500000	3.50	1.38	6.78^{-8}	1203.8	651.0
600000	1.50	5.92^{-8}	2.91	1647.2	897.3
700000	7.42^{-7}	2.92	1.44	1835.7	1002.1
800000	3.95	1.56	7.64^{-9}	1964.3	1073.5
900000	2.22	8.74^{-9}	4.29	2053.4	1123.0
1000000	1.30	5.13	2.52	2124.6	1162.5
1100000	7.92^{-8}	3.12	1.53	2160.3	1182.4
1200000	4.96	1.95	9.59^{-10}	2189.3	1198.5
1300000	3.19	1.25	6.16	2214.6	1212.5
1400000	2.10	8.25^{-10}	4.05	2217.2	1214.0
1500000	1.40	5.52	2.71	2221.2	1216.2
1600000	9.55^{-9}	3.76	1.85	2232.1	1222.3
1700000	6.61	2.60	1.28	2233.7	1223.1
1800000	4.62	1.82	8.93^{-11}	2232.9	1222.7
1900000	3.26	1.29	6.31	2241.4	1227.4
2000000	2.33	9.17^{-11}	4.50	2250.8	1232.7

TABLE 2-3. PULMONARY GASES AT EQUIVALENT ALTITUDES WHEN BREATHING AIR OR PURE OXYGEN.

Equivalent Altitudes		*Breathing*	*Tracheal Inspired* PO_2 *mm Hg*	*Alveolar*		*R**
Feet	*mm Hg*			PO_2 *mm Hg*	PCO_2 *mm Hg*	
Sea Level	760	air	149	103	40	.85
34,000	188	oxygen	141	101	40	
5,000	632	air	123	80	38	.87
36,500	167	oxygen	120	82	38	
10,000	523	air	100	61	36	0.90
39,500	145	oxygen	98	62	36	
15,000	429	air	80	46	33	0.95
42,000	128	oxygen	81	48	33	
18,000	380	air	70	38	31	0.98
44,000	117	oxygen	70	39	31	
20,000	350	air	64	34	30	1.00
45,000	111	oxygen	64	34	30	
22,000	321	air	57	30	28	1.05
46,000	106	oxygen	59	30	29	

* R = Respiratory Exchange Ratio ($\dot{V}CO_2/\dot{V}O_2$)

and falls below the limit that maintains the body in a physiologically safe condition.

For the unacclimatized man, an alveolar oxygen tension of less than 50 mm Hg is considered as approaching a severe state of hypoxia and an oxygen tension of 30 mm Hg is not adequate for supporting consciousness, and collapse is imminent. Theoretically, at a barometric pressure of 87 mm Hg (50,000 feet), with a normal carbon dioxide tension in the lungs of 40 mm Hg plus the water vapor tension of 47 mm Hg, even when breathing pure oxygen, the alveolar oxygen tension is reduced to zero and approaches a true state of anoxia. At 63,000 feet where the barometric pressure is 47 mm Hg, the lungs are completely filled with water vapor, theoretically, leaving no available room for other gases. Actually, under such a condition as this, not only is there the theoretical tendency for the body fluids and venous blood to boil, but outgassing of all dissolved gases in the venous blood, including oxygen, carbon dioxide and nitrogen will proceed outward at a vigorous rate through the lungs. This outgassing process becomes most extreme under conditions of a vacuum, such as in space flight conditions where the ambient barometric pressure is essentially zero. The term *ebullism* has been suggested for this unusual boiling phenomenon and unique medical syndrome.

The pressure of oxygen in the alveoli varies with the percentage of oxygen in the inspired air and the barometric pressure and, consequently, is subject to variations as either of these two factors changes. The carbon dioxide tension will decrease as the individual begins to hyperventilate with the onset of hypoxia, but the range of variation is small as compared to the extensive changes in alveolar oxygen tension. The water vapor in the alveolar air remains constant. At sea level, the alveolar partial pressures when breathing air are as follows:

$$P_{O_2} = 103 \text{ mm Hg};$$
$$P_{CO_2} = 40 \text{ mm Hg};$$
$$P_{H_2O} = 47 \text{ mm Hg; and}$$
$$P_{N_2} = 570 \text{ mm Hg}.$$

The equation for calculating the alveolar oxygen tension in mmHg, when inspired carbon dioxide is essentially zero, is:

$$P_{A_{O_2}} = (P_B - 47)\, F_{I_{O_2}} - P_{A_{CO_2}} \left(F_{I_{O_2}} + \frac{1 - F_{I_{O_2}}}{R}\right)$$

Where $P_{A_{O_2}}$ = Alveolar oxygen tension
P_B = ambient barometric pressure
$F_{I_{O_2}}$ = fraction of inspired oxygen (0.209 for air)
$P_{A_{CO_2}}$ = alveolar carbon dioxide tension
R = respiratory exchange ratio
47 = vapor tension of water 37° C.

When R is unity, this equation reduces to:

$$P_{A_{O_2}} = (P_B - 47)\, F_{I_{O_2}} - P_{A_{CO_2}}$$

When breathing 100% oxygen at any altitude, the above equation resolves to a simpler form:

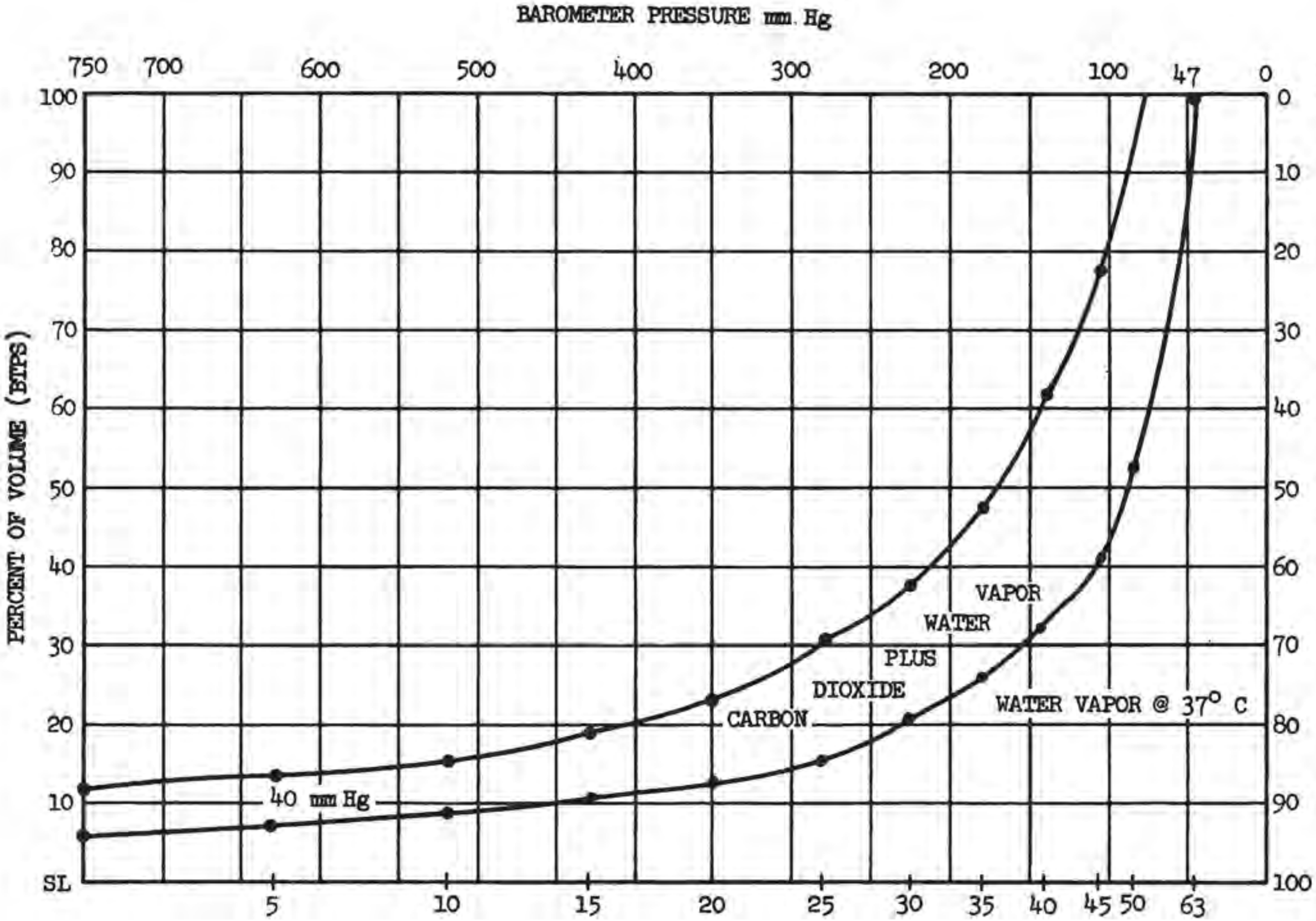
$$P_{A_{O_2}} = (P_B - 47) - P_{A_{CO_2}}$$

At sea level, the combined pressure of P_{CO_2} and P_{H_2O} is 87 mm Hg and occupies $\frac{87}{760}$ or 11% of the lung volume; oxygen occupies $\frac{103}{760}$ or 14%; and nitrogen, 75%.

At 18,000 feet, P_{CO_2} equals 31 mm Hg, P_{H_2O} remains 47 mm Hg, and the barometric pressure is 380 mm Hg. At this level $\frac{31 + 47}{380}$ or 21% of the lung volume is occupied by carbon dioxide and water vapor.

Figure 2-3 shows the increasing percentage of the lung volume occupied by water vapor and by both water vapor and carbon dioxide with decreasing barometric pressures (in which it is assumed that the P_{CO_2} remains constant at 40 mm Hg). It can be seen that water vapor alone occupies about 50% of the lung volume at an altitude of 47,000 feet and, without hyperventilation at this altitude, less than 15% of the volume is available for oxygen.

Between 30,000 and 40,000 feet, the automatic pressure-demand oxygen regulators (MD-1 or MD-2) are designed to deliver 100% oxygen under a slight "safety" pressure (3 to 4 mm Hg) to prevent inboard mask leakage. At altitudes above 40,000 feet, the positive pressure delivered to the mask increases with increasing altitude, as shown in table 2-4.



PERCENT OF VOLUME FOR AIR OR OXYGEN

ALT IN THOU		PER VOL BTPS $CO_2+H_2O(g)$
1.	SL	12
2.	5	14
3.	10	16
4.	15	20
5.	20	23
6.	25	31
7.	30	38
8.	35	48
9.	40	62
10.	45	78
11.	50	100

ALT IN THOU		PER VOL BTPS $H_2O_{(g)}$ @ 37° C
1.	SL	6
2.	5	7
3.	10	9
4.	15	11
5.	20	13
6.	25	16
7.	30	21
8.	35	26
9.	40	33
10.	45	41
11.	50	54
12.	63	100

The percent of the lung volume occupied by water vapor and carbon dioxide at various altitudes, assuming a constant alveolar carbon dioxide tension of 40 mm Hg.

Figure 2–3. Lung Volume Occupied by Water Vapor and Carbon Dioxide at Various Altitudes.

TABLE 2-4. TRACHEAL PARTIAL PRESSURE OF OXYGEN, PRESSURE BREATHING 100 PERCENT OXYGEN.

Altitude (Feet)	*Barometric Pressure (mm Hg)*	*Tracheal* Po_2 *100%* O_2 *(mm Hg)*	*Breathing Pressure Using Standard Air Force Oxygen Equipment (mm Hg)*	*Tracheal* Po_2 *Using Standard Air Force Oxygen Equipment*
40,000	141	94	4-8	98-102
43,000	122	75	11-14	86-89
45,000	111	64	15-18	79-81
48,000	96	49	23	72
50,000	87	40	30	70

It can be noted that, at 50,000 feet, a positive pressure of about 30 mm Hg is transmitted to the mask, resulting in a tracheal Po_2 of about 70 mm Hg, provided there is no excessive mask leakage. This is equivalent to breathing oxygen at 44,000 feet or breathing air at 18,000 feet. In all of these cases, this represents a severe degree of hypoxia, being compounded still further at 50,000 feet by the high degree of unsupported pressure breathing and its effect on the cardiovascular system. For these reasons, this type of pressure breathing at altitudes above 45,000 feet provides inadequate protection except for brief periods, in extreme emergencies, followed by immediate descent. For adequate protection, the pressure suit is mandatory to effectively bring the equivalent altitude for pulmonary oxygenation below 40,000 feet.

Oxygen Transport and Tissue Phase of Respiration

The quantity of gas that goes into solution, temperature remaining constant, is dependent on its solubility characteristics and is proportional to the partial pressure of the gas concerned (Henry's Law). However, far greater quantities of oxygen and carbon dioxide are carried in the blood than can be present in simple solution in the plasma. At sea level, when air is breathed, only 0.24 cc of oxygen and 2.5 cc of carbon dioxide is carried in 100 cc of blood in simple solution. Under the same conditions, however, 100 cc of blood actually contains about 18 to 20 cc of oxygen and 40 to 50 cc of carbon dioxide. This is 100 times the amount of oxygen and 20 times the amount of carbon dioxide that can be carried in simple solution. The ability of the blood to carry such a great load of oxygen is due to the hemoglobin contained in the red blood cells. Carbon dioxide is carried largely in the form of bicarbonate ions in the plasma and in the red blood cells.

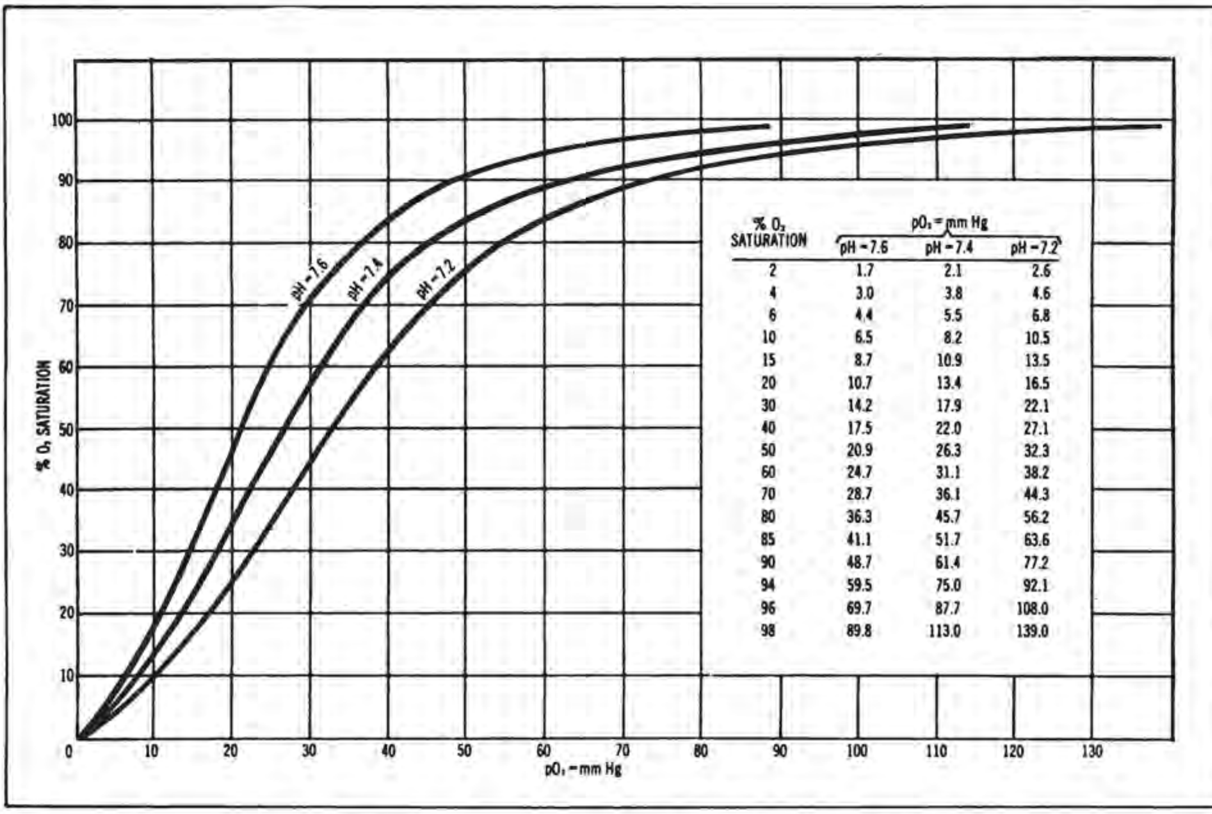
Oxygen combines reversibly with hemoglobin in a unique manner to form oxyhemoglobin. This is discussed in connection with the curves of dissociation of oxyhemoglobin in figure 2-4.

The combination of hemoglobin with oxygen is influenced by the partial pressure of oxygen in the surrounding medium. This has a direct effect on the amount of oxygen delivered to the tissues of the body at various altitudes.

It has been noted that, as the partial pressure of oxygen is lowered, little oxygen is released from hemoglobin until a partial pressure of 60 mm Hg or less is attained (figure 2-4, O_2 dissociation curve, pH 7.4). At this point, a more rapid evolution of oxygen commences and continues until 0 mm Hg is reached. The same observation can be made in the reverse direction—*i.e.,* the greatest absorption takes place between 0 to 40 mm Hg.

The oxygen-carrying capacity of hemoglobin is very sensitive to changes in the pH and Pco_2 of the blood (Bohr effect) as is apparent in figure 2-4.

For example, at an oxygen tension of 50 mm Hg, pH 7.2, the oxygen saturation is 75%, while at pH 7.6, the oxygen saturation is 90%. Carbon dioxide has a major influence



% O_2 SATURATION	pO_2 = mm Hg		
	pH - 7.6	pH - 7.4	pH - 7.2
2	1.7	2.1	2.6
4	3.0	3.8	4.6
6	4.4	5.5	6.8
10	6.5	8.2	10.5
15	8.7	10.9	13.5
20	10.7	13.4	16.5
30	14.2	17.9	22.1
40	17.5	22.0	27.1
50	20.9	26.3	32.3
60	24.7	31.1	38.2
70	28.7	36.1	44.3
80	36.3	45.7	56.2
85	41.1	51.7	63.6
90	48.7	61.4	77.2
94	59.5	75.0	92.1
96	69.7	87.7	108.0
98	89.8	113.0	139.0

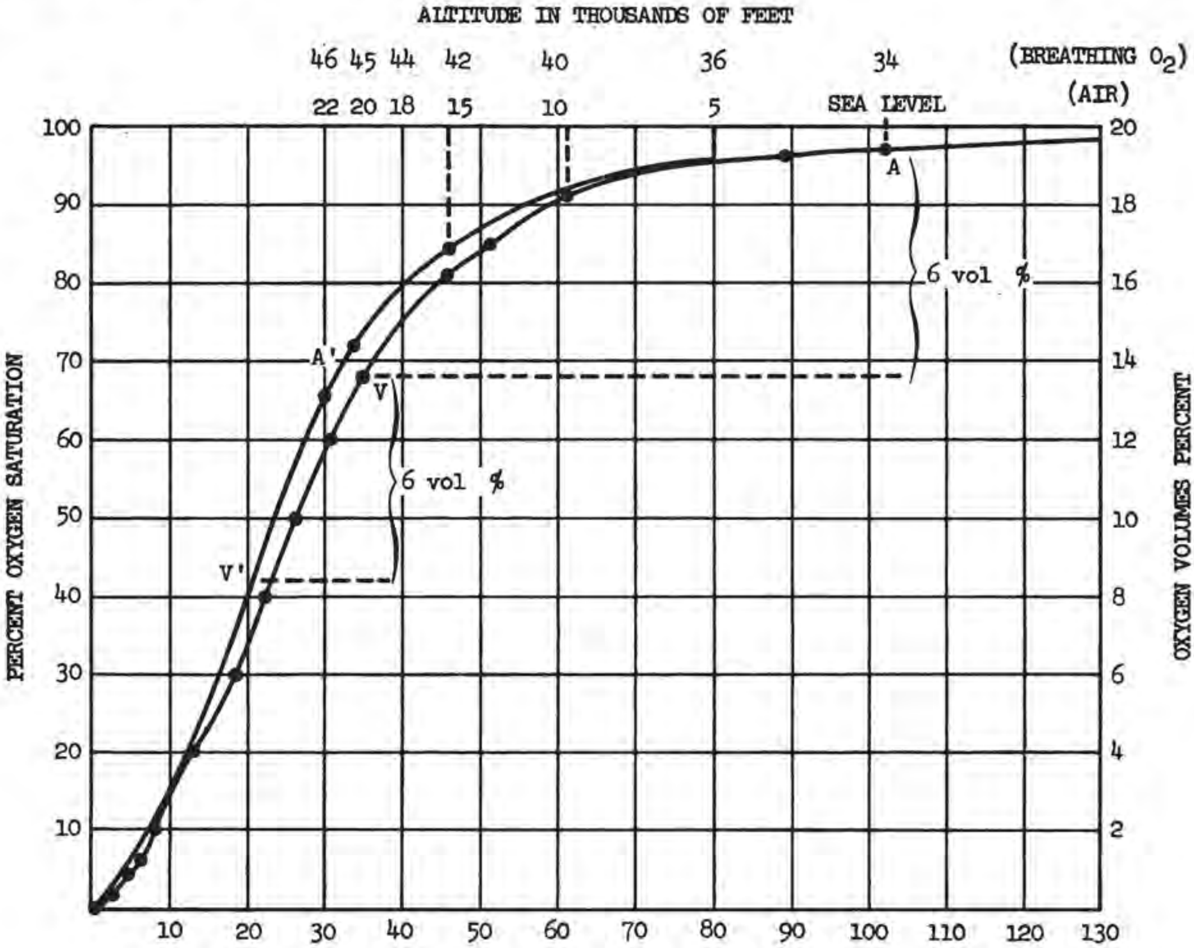
Figure 2–4. Oxygen Dissociation Curves for Human Blood.

on blood pH and on the oxygen dissociation curve. An increase in P_{CO_2} shifts the curve to the right toward the acid side (low pH) and, conversely, a low P_{CO_2} shifts the curve to the left toward the alkaline side (high pH).

Because of this, there must be a slight shift of the oxygen dissociation curve as blood passes through the arteries and veins between the lungs and the tissues. In the lungs, the uptake of oxygen and the release of carbon dioxide shift the curve to the alkaline side, permitting good oxygen loading. In the tissues, the uptake of carbon dioxide and release of oxygen tend to shift the curve to the acid side, favoring the unloading of oxygen at a higher oxygen tension. During muscular exercise, with an increase in carbon dioxide and acidity at the tissue level, this effect should provide a physiologic advantage for the delivery of oxygen. It has been shown, however, that the dilation and opening up of muscle capillaries and increased blood flow to the active muscles are much more significant in this respect.

Likewise, an increase in blood temperature shifts the curve to the right, again favoring the unloading of oxygen at metabolically active organs and tissues, while a decrease in blood temperature moves the dissociation curve to the left side of the diagram. This temperature effect can be an important consideration under conditions of hypo- or hyperthermia, cold or frozen extremities, etc.

The relationship between the oxygen dissociation curve, arterial and venous oxygen saturations, and equivalent altitudes in terms of the alveolar oxygen and carbon dioxide tensions is shown in figure 2–5 where the values from table 2–3 have been used. The normal oxygen dissociation curve (pH 7.4) indicates the arterial and venous points under sea level conditions and shows that,



V

	OXY PRESS	OXY SAT
1.	0	0
2.	2	2
3.	4	4
4.	6	6
5.	8	10
6.	13	20
7.	18	30
8.	22	40
9.	26	50
10.	31	60
11.	35	68
12.	46	81
13.	52	85
14.	61	91
15.	88	96
16.	103	97
17.	130	98

V'

	OXY PRESS	OXY SAT
1.	0	0
2.	30	64
3.	34	72
4.	46	84
5.	61	91
6.	88	96
7.	103	97
8.	130	98

The figure demonstrates the normal dissociation curve (pH 7.4) and the points on the shifted dissociation curve at various equivalent altitudes, breathing air or oxygen. The volumes percent scale is based on a blood oxygen capacity of 20 volumes percent (data from table 2-3).

Figure 2-5. Oxygen Dissociation Curves.

from arterial (A) to venous blood (V), the saturation decreases to approximately 70% with a decrease in oxygen content of about 6 volumes percent. At 20,000 feet while breathing air, or at 45,000 feet while breathing oxygen, the dissociation curve shifts slightly to the left because of the hypoxic hyperventilation which decreases carbon dioxide and increases pH. Here, the arterial saturation (A) is about the same as venous blood under sea level conditions. To deliver six volumes percent of oxygen to the tissues, blood flow remaining constant, the blood saturation must decrease to almost 40% saturation (V) with an oxygen tension of not much more than 20 mm Hg. By increasing the blood flow, *for example*, by doubling the cardiac output, the same quantity of oxygen can be delivered to the tissues with a net effect of decreasing the oxygen content by three volumes percent and raising the venous oxygen saturation and tension to about 55% and 26 mm Hg, respectively. Both the cardiovascular and ventilatory responses to hypoxia are important compensatory adjustments.

Furthermore, figure 2–5 shows that, at the critical hypoxia levels above 18,000 feet while breathing air and 44,000 feet while breathing oxygen, the arterial saturation points lie on the steep portion of the dissociation curve where the oxygen tensions are between 30 and 40 mm Hg. It is in this region of the curve that even a small decrease in the barometric pressure can result in a striking decrease in the arterial oxygen saturation. This is particularly true when breathing pure oxygen above 44,000 feet, for here each mm Hg change in the barometric pressure represents the same change in the oxygen tension, and a change of only 2 to 3 mm Hg can be the difference between consciousness and unconsciousness. This same concept holds true when pressure breathing at these or higher altitudes with a tight or leaky oxygen mask. Under these conditions, every mm Hg of oxygen counts, and even a slight drop in the mask pressure will immediately cause the arterial oxygen saturation to slide sharply down the dissociation curve to dangerously low levels. It is interesting to compare this type of situation with a change in altitude from sea level to 10,000 feet, *for example*, breathing air. In this case, a decrease of 40 mm Hg in oxygen tension has only a slight effect on the arterial oxygen saturation which decreases to about 90%. This important characteristic permits man to function effectively in a fairly broad pressure environment and is the very basis for the design of cabin pressurization systems permitting considerable latitude in the selection and control of pressure differentials for the cabin.

Figure 2–6 is a composite picture of both phases of respiration at rest, with the values of the gases involved at ground level. Hypoxia, discussed later, may result from a deficiency in either of the two phases of respiration.

Control of Ventilation

The control of respiratory rate and depth is complicated, but two of the important factors that influence the process are the chemical and psychic stimuli. An individual at rest ordinarily breathes at a rate of 12 to 16 times per minute with no conscious effort. The result is an exchange of 6 to 8 liters per minute (minute respiratory volume). With exercise, there is an increased demand for oxygen and for elimination of carbon dioxide. The body responds to this demand by an increase in ventilation and cardiac output. Figure 2–7 illustrates the changes in ventilation during work at ground level and altitudes up to 40,000 feet, while the subject breathes from an oxygen system.

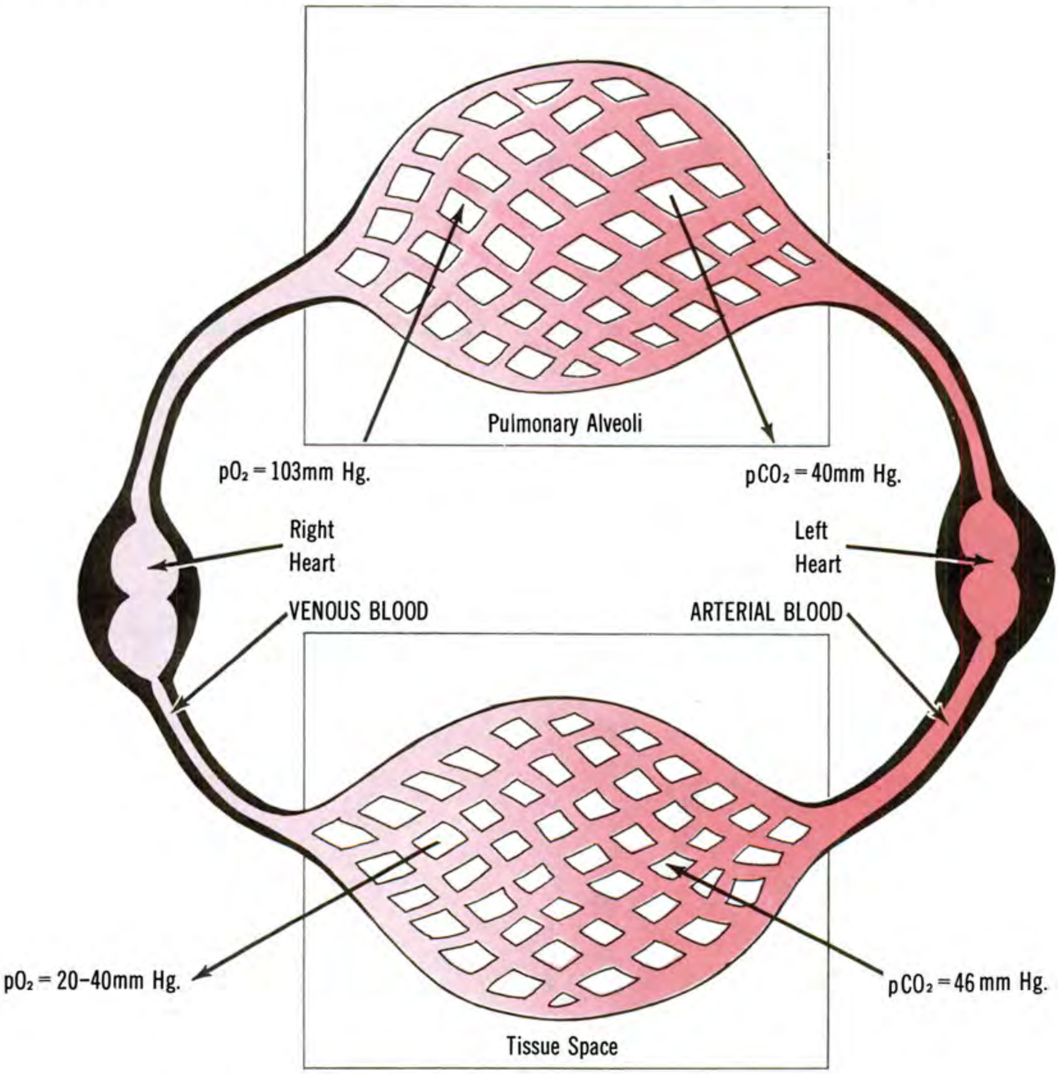
When hypoxia is not present, the minute respiratory volume does not change significantly with altitude up to 30,000 feet in the resting subject, but each increase in workload causes a rise in ventilation. Note that the curve remains rather constant for each workload up to 30,000 feet, and then there is a marked rise in ventilation between 30,000 and 40,000 feet. At 40,000 feet, even though 100% oxygen is breathed, the barometric pressure is so low that the alveolar oxygen

Mixed Venous Blood

O_2		
	Content	14 vol %
	Tension	36mm Hg
	Physical Sol	0.1 vol %
CO_2		
	Content	54 vol %
	Tension	46mm Hg
	Physical Sol	3.0 vol %
Hemoglobin		
	Content	15 gram %
	Oxy Hgb	70%
	Hgb	30%

Arterial Blood

O_2		
	Content	19 vol %
	Tension	100mm Hg
	Physical Sol	0.24 vol %
CO_2		
	Content	49 vol %
	Tension	40mm Hg
	Physical Sol	2.5 vol %
Hemoglobin		
	Content	15 gram %
	Oxy Hgb	96%
	Hgb	4%



Mechanics of gas exchange - Internal and external respiration

Figure 2-6. Phases of Respiration.

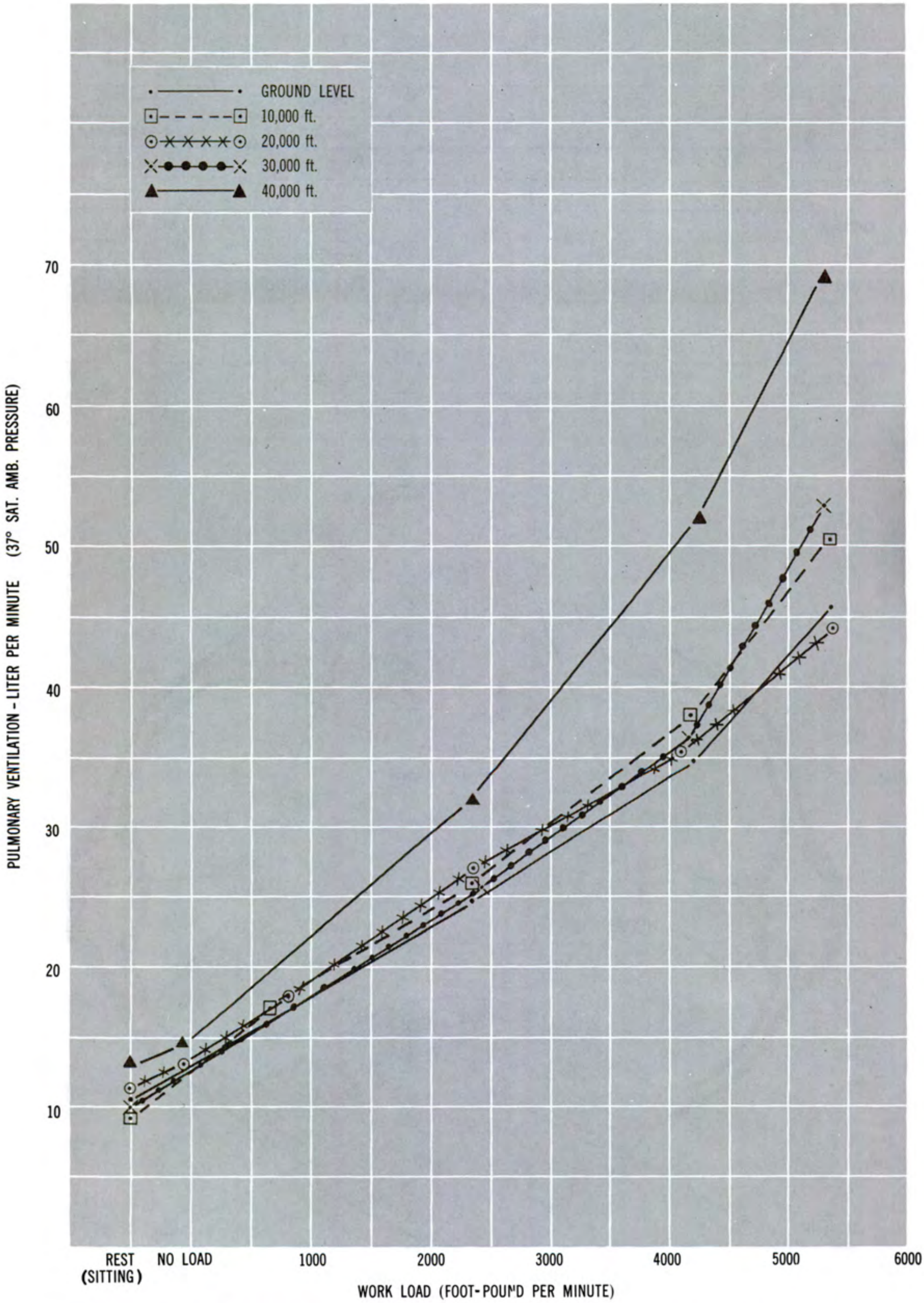


Figure 2–7. The Relation of Ventilatory Volume to Work at Various Altitudes.

tension is the same as at 10,000 feet while breathing ambient air. The disproportionate rise in minute respiratory volume for a given workload at 40,000 feet with the subject breathing 100% oxygen can be related to hypoxia.

Measurements taken on bomber crews and fighter pilots during flight showed minute respiratory volumes in the range of 7 to 15 liters per minute during periods of relative inactivity, the average being 12 liters per minute. When the subjects were active, the measurements ranged from 12 to 60 liters per minute, with an average of 25 liters per minute.

While breathing air at sea level, the partial pressure of oxygen in the arterial blood is normally about 100 mm Hg and oxygen lack (hypoxia) normally does not exist. The partial pressure of oxygen under this condition does not contribute to the control of respiration since the chemoreceptors in the aorta and carotid sinus primarily respond only to an abnormally low partial pressure of oxygen in the arterial blood. Instead, without hypoxia, the small fluctuations of carbon dioxide partial pressure, the pH of arterial blood, and the respiratory centers in the medulla play the major roles in regulating respiration under normal conditions at ground level. Not until the partial pressure of arterial oxygen has decreased below 80 mm Hg does a significant increase in ventilation begin while a person is at rest. This hypoxic stimulus for increased ventilation, however, results in the excessive blowing off of carbon dioxide which leads to hypocapnia, an increase in arterial pH, and an inhibitory effect on respiration. Thus, the net effect, even with severe hypoxia, is an increase in ventilation that is not nearly as great as it would be if the carbon dioxide and acid-base balance of the arterial blood were not concomitantly altered in a manner that antagonizes the hypoxic stimulus.

For the unacclimatized man, with ascent to altitudes above 8,000 feet while at rest, the oxygen tension in the inspired air is reduced sufficiently so that hypoxia begins to be a significant stimulus to respiration. Under conditions of exercise, this effect is much more pronounced and begins at lower altitudes. At altitudes where hypoxia is critical, the combination of hypoxia and the concomitant hyperventilation response usually presents a clinical picture that is difficult to differentiate from the hyperventilation syndrome seen; *for example,* in states of anxiety under normal oxygen conditions at ground level. This is characterized by lightheadedness, palpitation, and paresthesia of the extremities and perioral area. If excessive hyperventilation persists, carpopedal spasms, mental disorientation, and unconsciousness may occur. Often, the individual is not aware of overbreathing and may complain of a sensation of smothering. Under this condition of hyperventilation, particularly where hypoxia is not the primary contributing factor, the decrease in arterial carbon dioxide tension, the shift in pH, and the severe state of respiratory alkalosis result in a marked decrease in cerebral blood flow (cerebral vasoconstriction) and a decrease in brain oxygenation, even though the alveolar and arterial oxygen tensions may be high.

Excessive hyperventilation during flight can lead to serious and, possibly, disastrous consequences. On the other hand, under conditions of acute hypoxia, without the normal hypoxic stimulus for hyperventilation, man's altitude ceiling and the threshold for hypoxic unconsciousness, when breathing air, would be decreased from approximately 22,000 feet to 16,000 feet. As shown in table 2-3, the alveolar oxygen tension at 22,000 feet is approximately 30 mm Hg where unconscious collapse is imminent. At the same time, the alveolar carbon dioxide tension is reduced to about 28 mm Hg by the increased pulmonary ventilation. It can be shown by the alveolar equation that, if the ventilation did not increase and the alveolar carbon dioxide tension remained at 40 mm Hg, the alveolar oxygen tension would be reduced to 30 mm Hg at a barometric pressure of 412 mm Hg or 16,000 feet. In hypoxic situations such as this, a moderate hyperventilation response is not only normal and desirable but, in critical instances, it can be the margin between consciousness and unconsciousness. Also, adaptation to chronic hyperventilation, with renal readjustment of the acid-base balance back toward normal, is one of the key factors in man's ability to acclimatize and to work and live at high altitudes. Thus, there are important advantages as well as serious disadvantages in hyperventilation, depending on the circumstances. The hyperventilation syndrome is most undesirable and dangerous when there is no physiologic need for it to increase the arterial oxygen tension, such as psychogenic hyperventilation induced by apprehension, fear, and anxiety. With proper indoctrination and training in the use of oxygen equipment, most hypoxic situations can be avoided except in unforeseen or unavoidable emergencies, and a vital physiologic requirement for hyperventilation should not occur normally when good oxygen discipline is maintained.

The Pattern of Respiration and Its Significance

Inhalation in the normal resting subject is an active movement, while exhalation is almost wholly passive. During exercise, not only do the rate and volume of respiration change, but so does the pattern. This difference is illustrated in figure 2–8. During a single inspiration of a resting individual, the "instantaneous flow rate" increases from zero, at the beginning, to 20 or 30 liters per minute near the midpoint of inspiration and returns to zero at the end. An individual who is exercising moderately may have a respiratory volume of 25 to 45 liters per

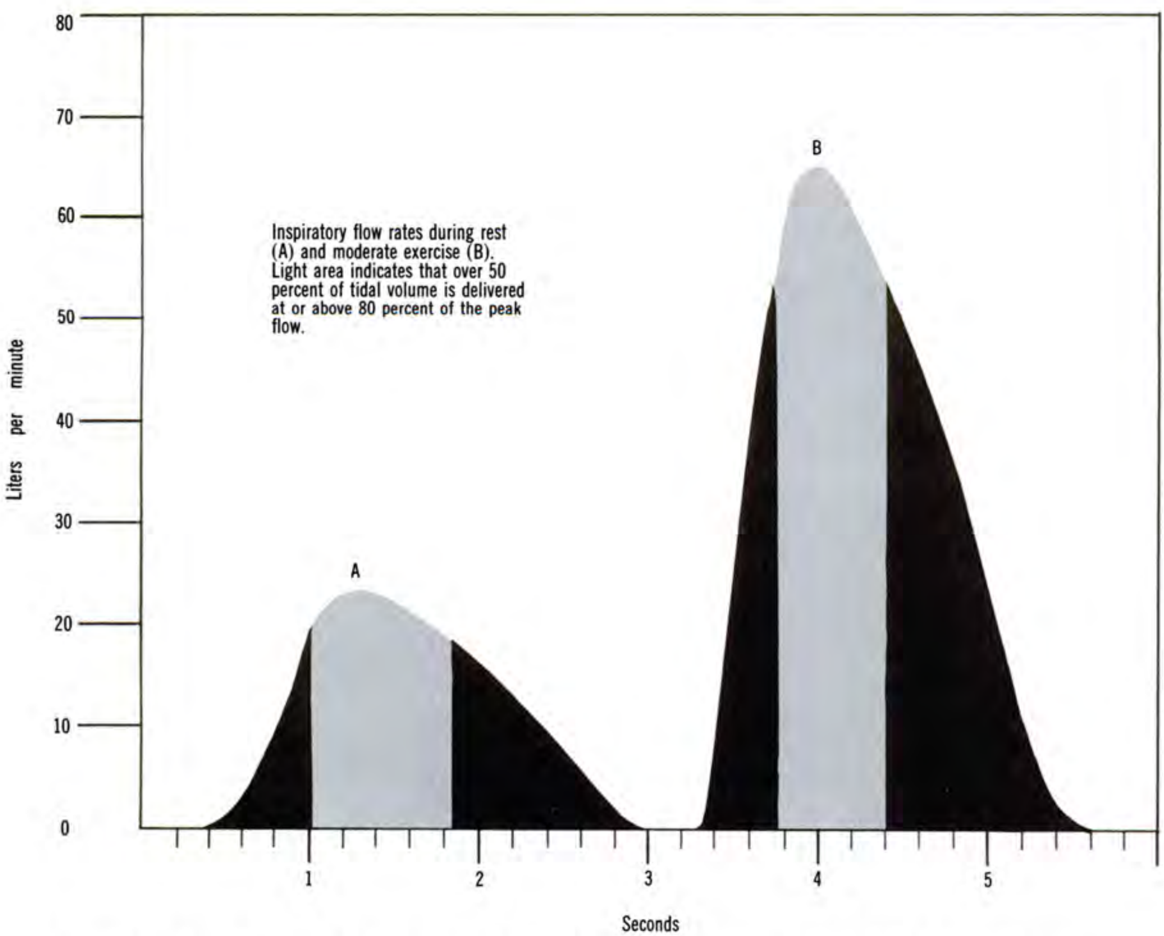


Figure 2–8. Changes in Respiratory Rate and Volume During Rest and Moderate Exercise.

minute and an instantaneous flow rate as high as 65 to 90 liters per minute. In general, to obtain the approximate maximal inspiratory or peak flow rates, minute respiratory volume (stated at STP) may be multiplied by 3.7 for a subject at rest and by 2.8 for an individual who is exercising.

Hypoxia

Altitude sickness in aviation is a syndrome that is usually acute and results from inadequate oxygenation of tissues secondary to a decreased partial pressure of oxygen in the inspired air. A syndrome, anoxia, meaning literally "without oxygen," is sometimes erroneously used to denote a deficiency rather than a lack of oxygen in the tissues. At altitudes below 55,000 feet, it is more exact to use the term "hypoxia," for even in such cases of acute altitude sickness, the tissues are never entirely without oxygen. At increasingly higher altitudes above 50,000 feet, however, tissue hypoxia verges into

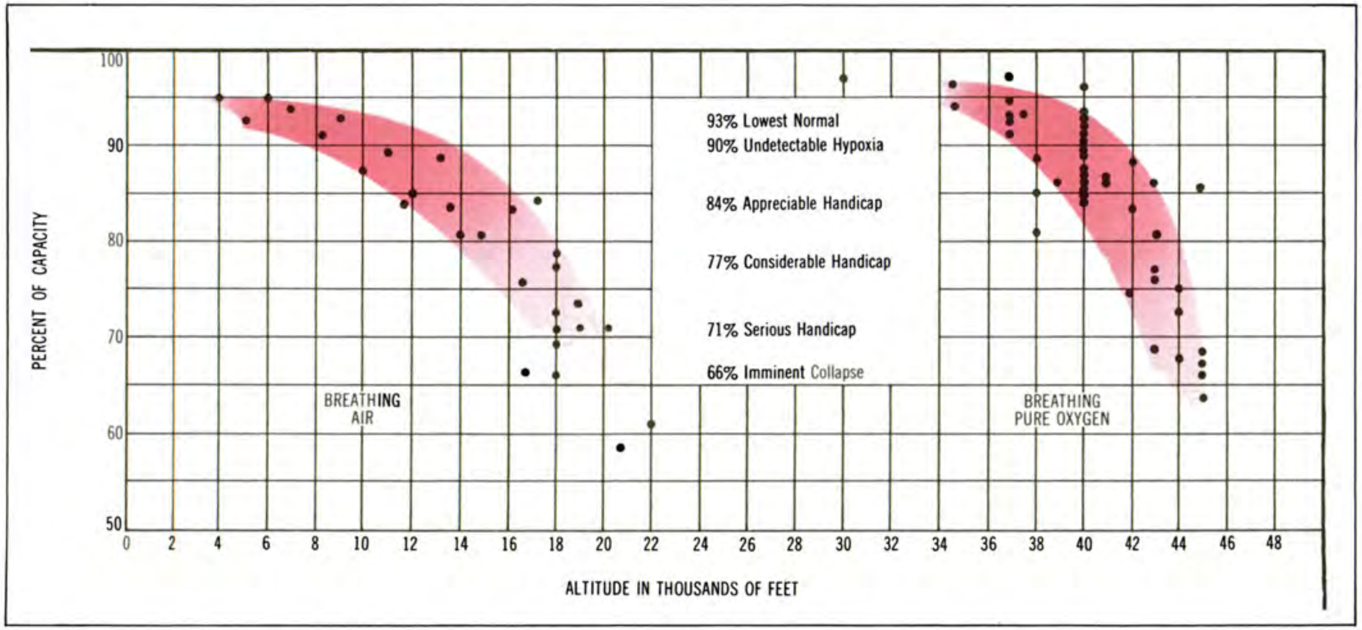


Figure 2–9. Oxygen Saturation (Percent of Capacity) of Arterial Blood and Range of Performance at Various Altitudes in Subjects Breathing Air and in Subjects Breathing Oxygen.

essentially true anoxia, regardless of whether ambient air or pure oxygen is being breathed.

a. Classifications of Hypoxia. Generally, there are four different classifications of hypoxia: *hypoxic, hypemic* or *anemic, histotoxic,* and *stagnant* hypoxia.

(1) *Hypoxic hypoxia* is caused by a decrease of the O_2 pressure in the inspired air or in the lungs, or by conditions which prevent or interfere with the diffusion of O_2 across the alveolar membrane. Examples of hypoxic hypoxia are: (a) A reduced atmospheric pressure and, therefore, a reduced alveolar Po_2 at altitude; (b) interference with respiration, as in asthma (where the tracheal or bronchial cartilage is constricted, thereby impeding proper lung ventilation), in pneumonia (where the collection of fluid in the alveoli hinders O_2 diffusion across the alveolar-capillary membrane), and in obstruction of air passages, such as by tumors or strangulation; (3) arterial venous shunts, as in congenital cardiovascular cases (see figure 2-9).

(2) *Hypemic or anemic hypoxia* is caused by a reduction in the capacity of the blood to carry a sufficient amount of oxygen because of a decreased hemoglobin content. *For example,* 1 Gm of hemoglobin normally carries 1.34 cc of oxygen, and a normal healthy man has the capacity to transport 20 cc of oxygen per 100 cc of blood. If the same individual were wounded and his hemoglobin reduced by one-half, due to blood loss, then he could transport only 10 cc of oxygen per 100 cc of blood. In the latter instance, there may be insufficient oxygen for the tissues, even though the blood is fully saturated with oxygen and no cyanosis is present. For cyanosis to occur, over 6 Gm of reduced hemoglobin per 100 cc of blood must be present in the capillaries of the skin. Carbon monoxide, nitrites, sulfa drugs, etc., cause the same type of hypoxia by forming compounds with hemoglobin and reducing the amount of hemoglobin available to form oxyhemoglobin.

(3) *Histotoxic hypoxia* ensues when the utilization of O_2 by the body tissues is interfered with. Alcohol, narcotics, and certain poisons, such as cyanide, interfere with the ability of the cells to make use of the O_2 available to them, even though the supply is normal in all respects. During histotoxic hypoxia, the venous O_2 HHb saturation is higher than normal because the O_2 is not being unloaded at the tissues. The tissues are unable to metabolize the delivered O_2.

(4) *Stagnant hypoxia,* like hypemic hypoxia, is due to a malfunction of the circulatory system, but differs in certain respects. While the oxygen-carrying capacity of the blood is adequate, there is an inadequate circulation of the blood. Such conditions as heart failure, arterial spasm, occlusion of a blood vessel, and the venous pooling encountered during positive G maneuvers and pressure breathing would predispose to stagnant hypoxia.

It is evident that all of these forms of hypoxia may become problems in flight. However, the most frequent and important type of hypoxia encountered is that caused by breathing air with a low partial pressure of oxygen. The result is the syndrome of "mountain" or "altitude" sickness.

Symptomatology of Hypoxia

The appearance of the signs and the severity of the symptoms of acute hypoxic hypoxia depends upon the following variables:

a. Absolute altitude.
b. Rate of ascent.
c. Duration at altitude.
d. Ambient temperature.
e. Physical activity.
f. Individual factors:
  (1) Inherent tolerance.
  (2) Physical fitness.
  (3) Emotionality.
  (4) Acclimatization.

Although it might seem that the higher the altitude the more marked the symptoms, it has been observed that, at rapid rates of ascent, still higher altitudes can be reached for brief periods of time before serious symptoms appear. Length of exposure is an important variable. Thus, while an altitude of 18,000 feet can be tolerated by most healthy persons for 30 minutes, severe symptoms may appear much sooner. A high surrounding temperature and physical exertion favor the development of symptoms at lower altitudes. Physical fitness and acclimatization from residence at high altitude raise an individual's "ceiling," while apprehension and lack of adequate physiological compensation by the respiratory and circulatory systems lower it.

For convenience, the symptomatology of hypoxia may be divided into stages related to the approximate pressure, the altitudes, and the oxygen saturation of the blood. As shown in table 2-5, the stages of hypoxia are:

(a) *Indifferent Stage.* The only adverse effect is on dark adaption, which is manifest at altitudes as low as 5,000 feet. It emphasizes the need for oxygen from the ground up during night flights, especially in the case of fighter pilots. Electrocardiographic changes may occur at altitudes as low as 5,000 feet; there is also an increase in the pulse rate.

(b) *Compensatory Stage.* Physiological compensations provide some defense against hypoxia so that effects are reduced unless the exposure is prolonged or unless exercise is undertaken. Respiration may increase in depth or slightly in rate, whereas the pulse rate, the systolic blood pressure, the rate of circulation, and the cardiac output increase.

(c) *Disturbance Stage.* In this stage, the physiological compensations do not suffice to provide adequate oxygen for the tissues—latent oxygen want becoming manifest. Subjective symptoms may include fatigue, lassitude, somnolence, dizziness, headache, breathlessness, and euphoria. Occasionally, there are no subjective sensations up to the time of unconsciousness. Objective symptoms include:

1. Special Senses. Both the peripheral and central vision are impaired and visual acuity is diminished. Extraocular muscles are weak and incoordinate, and the range of accommodation is decreased. Touch and pain are diminished or lost. Hearing is one of the last senses to be impaired or lost.

2. Mental Processes. Intellectual impairment is an early sign and makes it improbable for the individual to comprehend his own disability. Thinking is slow, and calculations of a navigator or bombardier are unreliable. Memory is faulty, particularly for events in the immediate past. Judgment is poor. Reaction time is delayed.

3. Personality Traits. There may be a release of basic personality traits and emotions as with alcoholic intoxication. There may be euphoria, elation, pugnaciousness, overconfidence, or moroseness.

4. Psychomotor Functions. Muscular coordination is decreased, and delicate or fine muscular movements may be impossible. This results in stammering, illegible handwriting, and poor coordination in aerobatics and in formation flying.

5. Hyperventilation Syndrome.

6. Cyanosis.

(d) *Critical Stage.* This is the stage in which consciousness is lost. This may be the result of circulatory failure ("fainter") or

TABLE 2-5. STAGES OF HYPOXIA.

Stage	*Altitude in Feet*		*Arterial Oxygen Saturation %*
	Breathing Air	*Breathing 100% Oxygen*	
Indifferent	0 to 10,000	34,000 to 39,000	95 to 90
Compensatory	10,000 to 15,000	39,000 to 42,500	90 to 80
Disturbance	15,000 to 20,000	42,500 to 44,800	80 to 70
Critical	20,000 to 23,000	44,800 to 45,500	70 to 60

of central nervous system failure ("nonfainter," unconsciousness with maintenance of blood pressure). The former is more common with prolonged hypoxia; the latter with acute hypoxia. With either type, there may be convulsions and eventual failure of the respiratory center, followed by cardiovascular failure and death.

Symptoms of Hypoxia

Unfortunately, man does not possess a built-in warning system to alert him to the onset of hypoxia and the danger of an hypoxic environment similar to the pain sensations of heat, cold, and certain noxious gases. On the contrary, hypoxia is painless, often resulting in a sense of well-being and the inability to recognize subjectively the onset of incapacitation. For these reasons, hypoxia in aviation is doubly insidious and dangerous.

Headache and lethargy are common complaints after a prolonged period of hypoxia. The headache is of general distribution, but is particularly acute in the frontal region. The best cure is sleep, but the administration of 100% oxygen is advisable if headache is severe. These symptoms have been explained on the basis of edema of the tissues, particularly the cerebral tissues, as a consequence of an increased permeability of the capillaries caused by the hypoxia. Nausea, vomiting, and severe prostration may also occur, but these usually clear up in 24 to 48 hours. Permanent cerebral damage resulting from altitude hypoxia has been comparatively rare, with only a few authenticated cases on record.

Individual variation in the ability to withstand hypoxia is considerable and accounts for variations in "ceiling." A large part of the tolerance is based on the adequacy of physiological adjustments, especially in breathing. The immediate result of deeper breathing is an increase in the pressure of oxygen in the lungs and increased alkalinity of the blood, owing to the hyperventilation effect. The latter favors uptake of oxygen by the hemoglobin. At such extreme altitudes as 40,000 feet where 100% oxygen must be breathed, the total pressure in the alveoli equals the sum of the partial pressures exerted by water vapor, carbon dioxide, and oxygen. The pressure of the water vapor is relatively constant, tending to correspond to a saturated state of 37°C. Consequently, lowering of the partial pressure of carbon dioxide, such as occurs in deep breathing, will increase the partial pressure of oxygen in the lungs by an approximately equivalent amount.

Inexperienced personnel collapse more frequently at intermediate altitudes than do experienced persons. The factors involved in such collapse are primarily psychogenic. The hyperventilation produced by hypoxia ordinarily lowers alveolar carbon dioxide enough to produce only minor symptoms, such as dizziness. However, a person who is apprehensive may hyperventilate to a greater extent and produce a degree of hypocapnia associated with more marked symptoms. Such hypocapnia, added to the splanchnic vasodilation, which is a frequent response to fear, may bring about collapse.

Prophylaxis and Treatment of Hypoxic Hypoxia

The treatment of hypoxia requires the administration of 100% oxygen by inhalation. If respiration has ceased, artificial respiration, along with the simultaneous use of 100% oxygen is indicated. If peripheral circulatory failure persists, the type must be determined and treatment given accordingly.

The prevention of hyperventilation in flying personnel is largely a matter of indoctrination. This is accomplished by instructing personnel in the proper use of oxygen equipment. The principal types of this equipment in the Air Force are described and illustrated on the pages that follow.

Recovery from hypoxia is usually rapid when sufficient oxygen is supplied. An individual on the threshold of unconsciousness may regain his full faculties within 15 seconds after he receives an abundance of oxygen. Experience has shown that, if a hypoxic patient breathes oxygen deeply, he may occasionally experience a flash of dizziness, but this usually passes immediately and is followed by complete restoration of normal function. Known as the "oxygen paradox," this effect is probably caused by the cessation of the hypoxic respiratory drive that is mediated through the aortic and carotid bodies (chemoreceptors) with the first breath of oxygen. The normal respiratory drive, maintained predominately at the respiratory centers in the medulla by pH and P_{CO_2}, is now absent, due to the recent hypoxic hyperventilation and the concomitant alkalosis and hypocapnia.

Pressure Breathing

To prevent the effects of hypoxia above 40,000 feet some method of increasing the partial pressure of alveolar oxygen must be used. One method is positive pressure breathing by using an oxygen system that delivers 100% oxygen at greater than ambient pressures. Special pressure breathing regulators, mask, and mask valves are required.

In continuous positive pressure breathing, the process of breathing becomes more difficult at increasingly higher breathing pressures. The normal process of involuntary active inspiration and passive expiration is changed to a relatively passive, yet conscious inspiration and a very active expiration. Intermittent positive pressure breathing can partially compensate for this change in breathing mechanics by using a regulator which delivers oxygen under pressure only during inspiration. Therefore, both inspiration and expiration become passive phenomena. This quite commonly leads, however, to a symptomatic hyperventilation, which is one of the major disadvantages of intermittent positive pressure breathing.

Another major drawback is that intermittent positive pressure breathing provides a much lower mean mask pressure when compared with continuous positive pressure breathing systems. This means that the positive pressure portion of the intermittent cycle must be set at a higher level to bring the mean pressure up to the required magnitude. The *mean* mask pressure that is maintained during the complete respiratory cycle by positive pressure breathing is the important point of reference for evaluating alveolar oxygen pressure and the effectiveness of arterial oxygenation. Continuous positive pressure breathing provides a mean mask pressure that is nearly equal to the pressure delivered by the regulator, depending mainly on the tightness of the mask fit and the amount of mask leakage. Intermittent positive pressure breathing, on the other hand, can maintain a mean mask pressure that is only about one-third to one-half the peak pressure. For these reasons, continuous positive pressure breathing is the method of choice for use at high altitudes.

Breathing against continuous positive pressure is fatiguing and, because of the abnormal pressure relationships that are established between the lungs and the rest of the body, man's practical tolerance to pressure breathing and excessively high intrapulmonic pressures is limited and depends, in part, on his subjective response, his physical fitness, and the extent of cardiovascular compensations that can be brought into play for maintaining an adequate circulating blood volume. In this regard, the most efficient type of breathing pattern is worth consideration. If a rapid inspiration is followed by a prolonged expiration, the mean mask and intrapulmonic pressure of oxygen can be maintained at a high level, but there will also be an increase in the mean intrathoracic (intrapleural) pressure, somewhat similar to a valsalva maneuver. This restricts normal venous return to the thorax and flow of blood through the lungs, and results in an increased venous pressure and decreased cardiac output. On the other hand, if the breathing pattern is changed to a relatively slow inspiration, followed by a rapid expiration, the mean mask and intrapulmonic pressures will be only slightly lower, but the mean intrathoracic pressure will be considerably reduced, since considerably less pressure is transmitted across the elastic, expanding lungs to the heart and great vessels within the thorax. This will allow higher oxygen pressures to be used and, at the same time, tend to lessen somewhat the undesirable circulatory effects. This, however, should not imply that, under the conditions of positive pressure breathing, *complete* relaxation of the thoracic and abdominal muscles during inspiration is desirable or even possible. The tensed abdominal muscles provide considerable support for the diaphragm, the venous vascular system, and venous return to the thorax. If allowed to relax completely, excessive pooling of blood below the diaphragm can result in a marked decrease in venous return and cardiac output. Likewise, the tense thoracic and diaphragmatic musculature helps to prevent excessive overdistention of the lungs and helps to maintain, as well as possible, the lung volumes within their relatively normal relationships, as shown in figure 2–1.

Ordinarily, mask pressures of 15 to 30 mm Hg (8 to 15 inches water) can be tolerated for limited periods. Above 30 mm Hg pressure, it has been shown that, besides fatigue caused by pressure breathing at these higher levels, other symptoms may occur. At these pressures, subjects commonly complain of being overinflated and, concurrently, a feeling of congestion in the region of the frontal sinuses. At higher pressures, there may be pain occurring in the ears and in the posterior pharynx as a result of overdistention.

This pain in the posterior pharynx commonly has been the cause for termination of flight when attempts were made to pressure breathe against 60 mm Hg. At pressures between 60 and 100 mm Hg, there is the great danger of parenchymal lung damage secondary to overexpansion unless counterpressurization is applied. Perhaps the greatest limitation to pressure breathing is the effect on the cardiovascular system. Increasing the intrathoracic pressure by pressure breathing results in an increased intrapleural pressure which tends to compress lung tissue. This offers considerable resistance to the flow of blood through the lungs which, in turn, increases the venous pressure. As a result, cardiac output is decreased and a pooling of blood occurs in the extremities, but more extensively in the larger vessels in the abdomen.

It is known that blood displacement by pressure breathing may lead to a loss of consciousness. This effect upon the cardiovascular system is the greatest limiting factor in pressure breathing. Therefore, for flights of any duration over 40,000 feet, it is necessary to pressurize the person either by means of a counterpressurization suit or a pressurized cabin. The latter has the advantage of making it possible to fly unencumbered ("shirt sleeve") above 50,000 feet without the continuous use of oxygen equipment, provided the cabin pressure is kept under 10,000 feet (523 mm Hg). According to current directives, it is not permissible to fly above 50,000 feet, regardless of cabin altitude, unless the flier is protected by a pressure suit or capsule in the event cabin pressure is lost.

In general, the pressurization of aircraft cabins during high altitude flights affords a safe and comfortable environment for the crews and passengers, but the extent to which an aircraft cabin can be pressurized is limited, primarily, by engineering, mechanical, and structural considerations. For these reasons, an ideal sea level pressure within an aircraft cabin at high altitudes is either prohibitive or impractical. Instead, a compromise must be made between this ideal pressure and the physiologic limits beyond which a flier cannot be safely exposed. The maximum differential pressure between the cabin and ambient pressures is limited by the type of aircraft and the type of mission for which it is designed to fly, such as transport and commercial airliners, high altitude bombers, and fighter aircraft. These limiting pressure differentials range from about 9 psi for commercial and other comparable military aircraft to 5 psi and 2.75 psi for military aircraft, depending on the flight situation. Because of this, as shown in figure 2–10, the higher the flight altitude the higher also must be the cabin altitude if the limiting pressure differential is not to be exceeded. The minimum pressure differential of 2.75 psi permits flights to any altitude with a cabin altitude that will not exceed 40,000 feet. In this situation pressure breathing is not required but pure oxygen must be breathed to avoid hypoxia, and decompression sickness is a serious possibility without adequate denitrogenation before ascent. With a 5 psi differential pressure, regardless of the flight altitude, the cabin will always remain below an altitude of 30,000 feet, thereby reducing the probability of developing decompression sickness.

One potential hazard inherent in pressurized cabins is a sudden loss of pressure due to mechanical or structural defects or damage by gunfire, that may rapidly subject the pilot, crew, and passengers to altitudes where useful consciousness and life cannot be sustained. For this reason, there must be provided emergency oxygen and protective equipment which is adequate within the altitude profile of the aircraft. Between

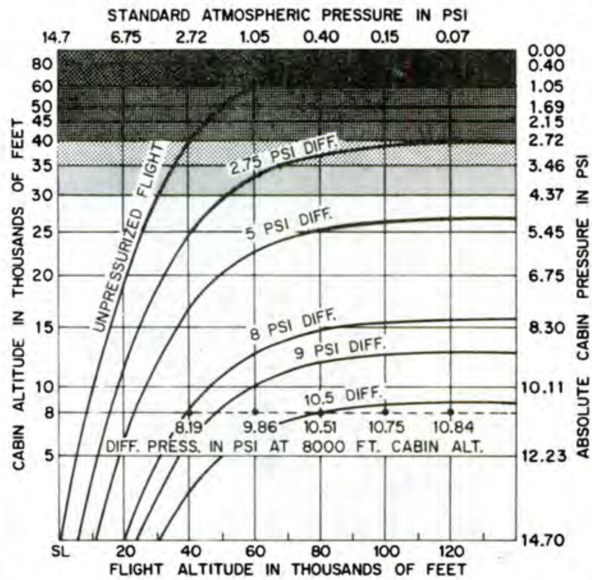
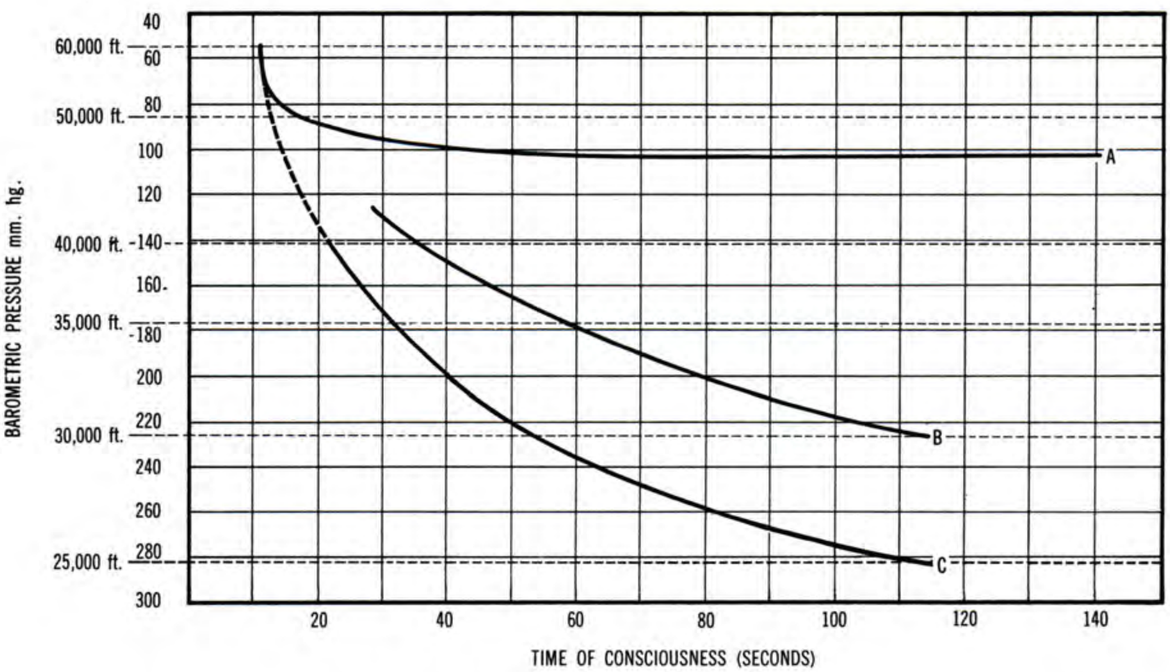


Figure 2–10. Cabin Pressure Schedules and Physiologic Thresholds at Various Flight Altitudes.



A. BENZINGER - 100% Oxygen at ambient pressure (rapid decompression from 40,000 ft.)

B. HALL - Air breathing (mask removal at altitude)

C. WILSON and COMFORT - Air breathing (rapid decompression from 10,000 ft.)

Figure 2–11. Time of Consciousness With Varying Types of Exposure at High Altitude.

40,000 and 50,000 feet, pressure breathing regulators will supply enough pressure to the pilot and/or crew for them to remain conscious during an immediate emergency descent to below 40,000 feet. However, sustained flight at these altitudes cannot be safely accomplished by pressure breathing.

Above 50,000 feet, pressure breathing is of little value since it is impossible to tolerate the amount of positive pressure necessary to prevent severe hypoxia without counterpressure. It is for this reason that all pilots and crews flying in aircraft without capsules above 50,000 feet are required to wear a counterpressurization garment of some type. These suits must inflate automatically in the event of a loss of cabin pressurization, and current suit types must offer the possibility of mission completion.

The likelihood of a sudden exposure to "critical altitudes" necessitates familiarity with the use of oxygen equipment and current pressure suits since, without this equipment, less than 15 to 30 seconds may elapse between the time of the decompression and loss of consciousness. Figure 2–11 shows the times of consciousness with varying types of exposure at high altitudes.

Oxygen Equipment

From the preceding discussion of the principles of respiratory physiology in aviation, it is evident that to produce efficient protective equipment for flight at high altitudes, engineers and physiologists must work together. With the evolution of oxygen equipment, man's altitude ceiling has been increased progressively.

In general, an oxygen system in an aircraft consists of containers for storing the oxygen supply, tubing to conduct the oxygen from the main supply to a metering device, a metering device to control the flow of oxygen, and a mask to direct the oxygen to the flier's respiratory system.

The first equipment used by the Air Force to protect fliers against reduced partial pressure of oxygen at high altitude was a simple tube connected through a valve type of metering device to a cylinder containing oxygen under high pressure. The maximum pressure in the oyxgen bottle was 1,800 psi. This tube was fitted with a pipe stem through which a continuous flow of oxygen was delivered into the user's mouth.

Although the system served its purpose by improving the flier's condition up to about 20,000 feet, it had the following disadvantages:

a. It did not adequately protect the normal nose-breathing individual.

b. Oxygen delivered during expiration, which is about half of the total time, was wasted.

c. The pipe stem was uncomfortable to hold between the teeth for long periods, especially in the unheated aircraft cockpits of the early days.

Continuous-Flow Oxygen System

In military aircraft, there is an obvious advantage in keeping the weight and space requirements of the oxygen system to a minimum. This increases the tactical efficiency of the aircraft by affording space for additional fuel to prolong the range of flight, for additional bomb loads, or for increasing the maneuverability essential in fighter aircraft. To economize on weight and space and to increase the altitude ceiling, a method was needed to restrict oxygen flow to a volume approaching the actual needs of an individual for a given altitude.

This requirement was quickly met by the design of a lightweight oronasal mask (figure 2–12), through which a continuous flow of oxygen was delivered to the flier. Attached to this mask was a rebreather bag (rubber bag of about 800 cc capacity) into which the first part of the exhaled gas was directed. Since this gas was from the upper part of the respiratory system, it consisted primarily of unused oxygen.

The rebreather system economizes by:

a. Reusing the oxygen contained in the respiratory dead space.

b. Supplying a reservoir to collect the volume of gas that flows from the oxygen cylinders during the expiratory phase of the breathing cycle.

Figure 2–12. A–8B Constant Flow Oxygen Mask.

The mask is equipped with sponge-rubber discs that serve as valves, through which the latter portion of the exhaled air is blown off. They also serve as inspiratory ports for the entrance of ambient air when inspiration is not fully satisfied by the contents of the rebreather bag and the flow of oxygen from the regulator.

To maintain continuous flow of oxygen at various altitudes, the main oxygen supply is equipped with a metering device or oxygen regulator (figure 2–13). The regulator includes a valve that is opened or closed manually to compensate for changes in altitude. With this system, oxygen is delivered to the valve at a constant pressure and is unaffected by changing pressure within the cylinder as the supply is consumed. The flow gauge on the regulator is calibrated in thousands of feet. The flier sets the valve to correspond to his flight altitude and thus receives the proper amount of supplementary oxygen for that altitude. In another type of continuous-flow regulator, the A–11, the oxygen is controlled automatically rather than manually.

As discussed earlier in this chapter (see "Control of Ventilation"), under conditions of breathing 100% oxygen at ambient pressure, man can ascend to 40,000 feet and be in approximately the same condition as when breathing air at 10,000 feet. Since the continuous-flow system supplies 100% oxygen, it may be assumed that 40,000 feet is the upper limit for use of the equipment. Basically this is true, but the inherent characteristics of the standard form of the system make it necessary to limit this assumption to conditions of rest. Therefore, it is adequate for passengers in transport aircraft below 30,000 feet because of the marginal degree of safety at higher altitudes in terms of mask fit and mask leakage.

Figure 2–13. Oxygen Regulator (Limited Standard).

Additional activity required of crew members in military aircraft may create a greater demand for supplemental oxygen than that supplied by the regulator and result in excessive inspiration of ambient air through inspiratory ports, thus producing hypoxia. A mask fit which will prevent inboard leakage is difficult to obtain when the crewmember is active, and this becomes an important factor at higher altitudes where any leakage around the edge of the mask will result in dilution of the oxygen concentration supplied. In view of the practical experience in military aviation, an arbitrary altitude ceiling of 25,000 feet has been established for this type of equipment.

The continuous-flow system, commonly, is installed in cargo, air evacuation, and transport aircraft where it serves as a simple system that can be operated successfully, even by individuals who have not been especially trained in its use. As long as the limitations discussed above are observed, it is a good method of supplying oxygen for certain types of flights at moderate altitudes.

In the early part of World War II, it became apparent that aircraft would be operating in the altitude range above 25,000 feet. Above this critical altitude, the introduction of even small amounts of ambient air into the respiratory passages was hazardous. Thus, it became necessary to attack the problem of inboard mask leakage if flights above 25,000 feet were to be feasible.

Demand-Type Oxygen System

A major improvement over the continuous-flow oxygen system is the demand-type oxygen system. This system delivers oxygen only during the inspiratory phase of the breathing cycle. Extensive physiological and engineering tests indicated that this method of delivering oxygen at high altitudes assured the flier of receiving 100% oxygen as long as an airtight face-to-mask seal could be maintained. Many design and engineering problems were involved in developing this system to a stage where it was satisfactory for use in military aircraft. The pressure of wartime and the urgent necessity for standardization of this equipment made it possible to install the first form of the demand system in combat aircraft in a remarkably short time. Improvements were made as the need for them became apparent during service tests under combat conditions, until the present demand-oxygen system was finally evolved.

The demand-oxygen mask is a simple mechanism designed to fit comfortably over the face of the wearer (figure 2–14). It contains a single flapper valve, seated in the base of the mask facepiece, which permits all of the expired air to be blown off to the outside atmosphere. During inspiration, the flapper seals tightly against the valve seat and no ambient air can be admitted to the mask through this channel.

The metering system that controls the flow of oxygen to the mask is called the diluter demand regulator (figure 2-15). This regulator is a fairly simple mechanism operated by normal changes in pressure occurring during the breathing cycle. Basically, it consists of a round box with a thin rubber diaphragm stretched across the front. Attached to the diaphragm is the lever of a valve that opens or closes the port that leads to the pressure reduction stage of the regulator.

Figure 2-14. A-14B Oxygen Mask (Limited Standard).

When the mask is attached to the regulator through a hose connection and the wearer inhales, a slight negative pressure is created within the regulator. This negative pressure draws the diaphragm in and changes the position of the valve so that an opening is created to the pressure reduction stage containing oxygen under pressure, and this oxygen flows through the regulator. The initial chamber of the regulator is a pressure reduction stage where oxygen cylinder pressure is reduced to a lower constant pressure, providing a relatively fixed pressure behind the diaphragm-operated valve.

Barring mechanical difficulties in the regulator itself, the only site of inward air leakage is around the face-to-mask seal. A number of different mask designs were tried until one was standardized which met the requirements for comfort and effective seal on the majority of types of faces. However, no matter how carefully such a mask is fitted, a minute leakage seems to be inevitable. This leakage factor makes it necessary, in the interest of safety, to limit the use of the diluter-demand oxygen system to altitudes below 35,000 feet.

Cylinder oxygen is further conserved in the demand system by making use of the oxygen present in ambient air at altitudes up to 34,000 feet where 100% oxygen is required. The diluter mechanism that mixes air and oxygen consists of a metal bellows attached to valves over both air and oxygen ports. As the flight altitude increases, trapped air in the bellows expands causing the bellows to operate these two valves. Thus, during ascent, the oxygen valve opening is gradually increased while the air inlet is reduced, thereby increasing proportionately the concentration of oxygen delivered to the mask.

The percentage of oxygen required for any given altitude has been determined by physiological experiments, and the design of the diluter mechanism of the regulator is based upon these data. A gradually changing mixture of air and oxygen is delivered up to about 30,000 feet, at which altitude the air inlet is closed completely and 100% oxygen is delivered. The user can change, at any time, the dilution lever on the side of the regulator from the "normal" diluting position to the "100% oxygen" position which will close off the air inlet and provide 100% oxygen at any altitude.

For the treatment of mild hypoxia, below 35,000 feet, the demand regulator is provided

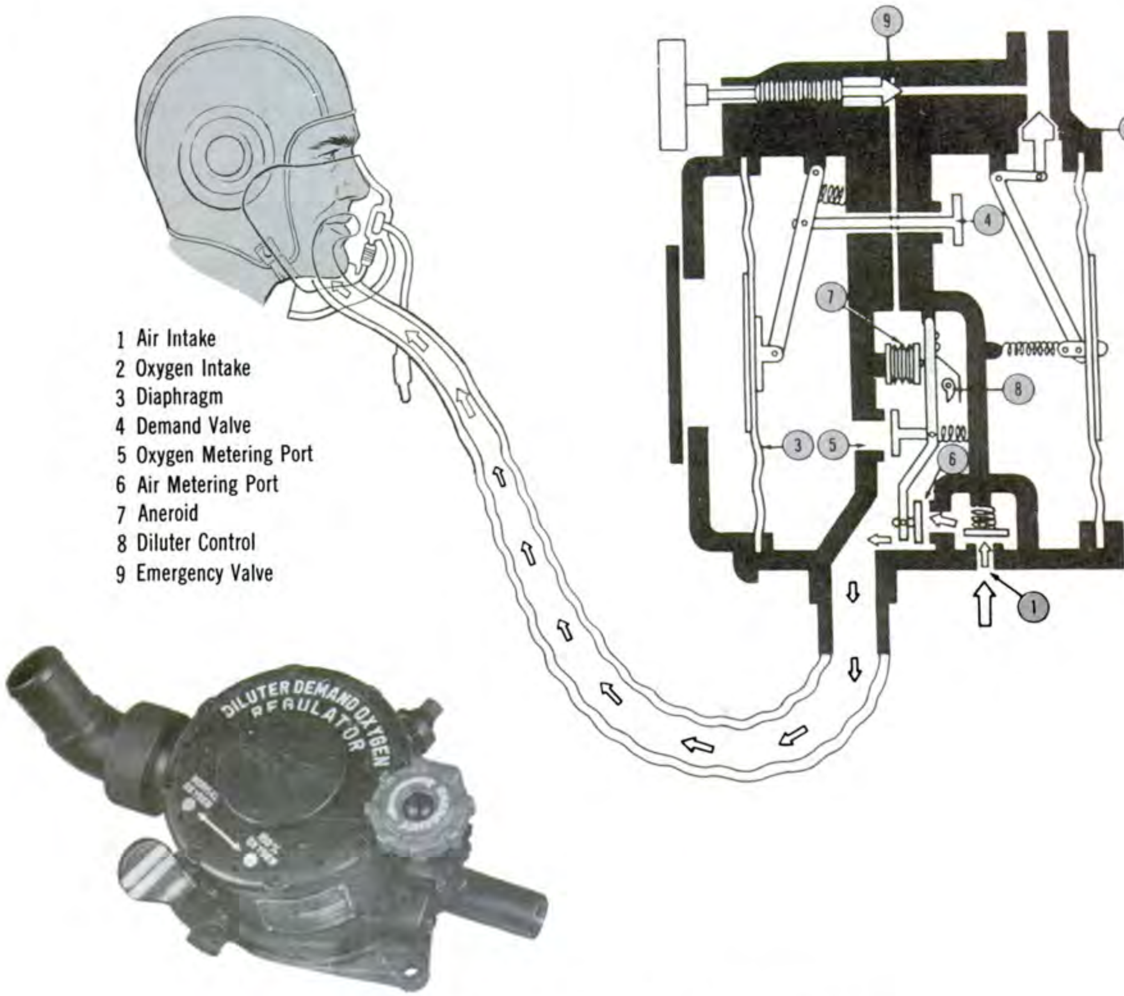


Figure 2-15. Diluter Demand Oxygen Regulator.

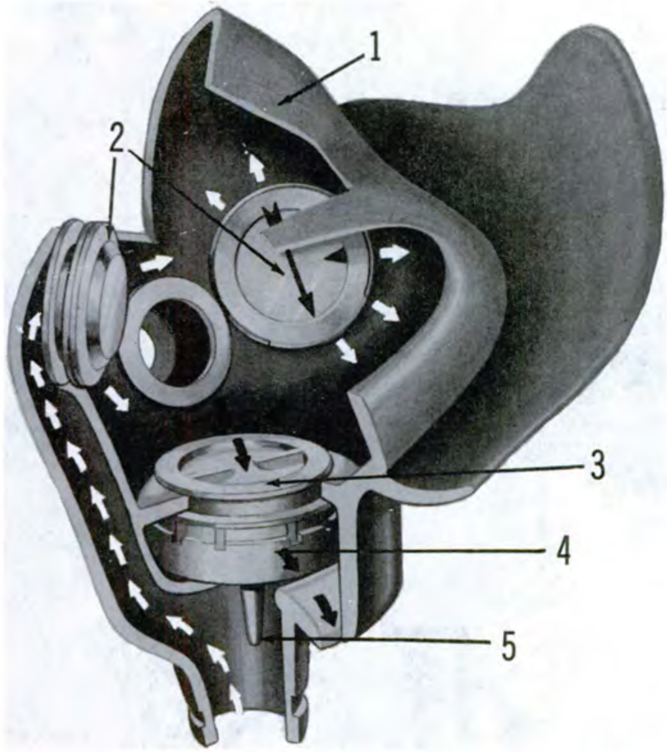
with an emergency valve. When this valve is opened, a large volume of oxygen in a continuous flow may be obtained quickly. It is sufficient to revive an hypoxic individual in a few seconds under most conditions, and maintain normal arterial oxygen saturation, even with a pulmonary ventilation rate equivalent to that of moderate exercise. It should be kept in mind that indiscriminate and excessive use of the emergency valve is extremely wasteful of oxygen and, if left open unnecessarily, can deplete the aircraft oxygen supply quickly.

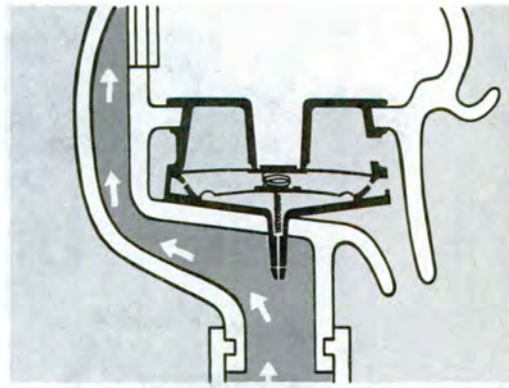
To maintain fliers in a normal condition at altitudes above 34,000 feet, two requirements must be fulfilled:

a. Up to 40,000 feet, inboard mask leakage must be eliminated so that 100% oxygen can be delivered to the lungs with every breath.

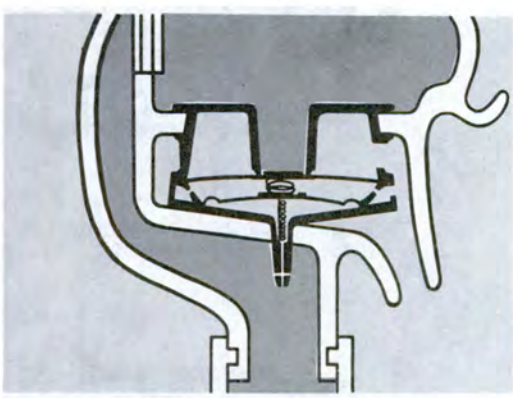
b. Above 40,000 feet, oxygen must be delivered to the mask at pressures in excess of ambient. If sufficient pressure is added to the mask, positive pressure breathing will maintain a normal alveolar partial pressure of oxygen.

From a mechanical standpoint, the same modifications fulfill these two requirements. It is possible to eliminate inboard mask leakage by supplying oxygen at a small positive pressure—about 2 inches of water. Under these conditions, if the mask-to-face

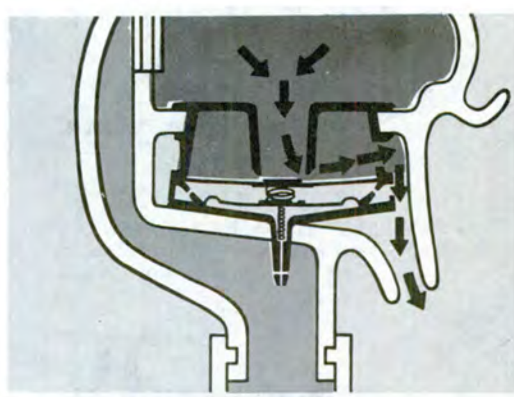




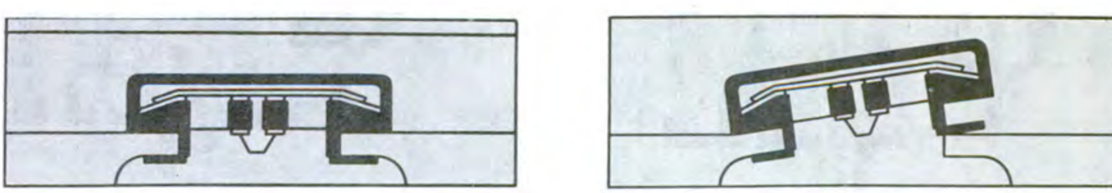
INHALATION. The inlet pressure is greater than the pressure inside the mask during inhalation. The compensating diaphragm is pushed up against the main diaphragm, closing the exhalation valve.



PAUSE BETWEEN INHALATION AND EXHALATION. The inlet pressure and the pressure inside the mask are momentarily equal. The valve remains closed.

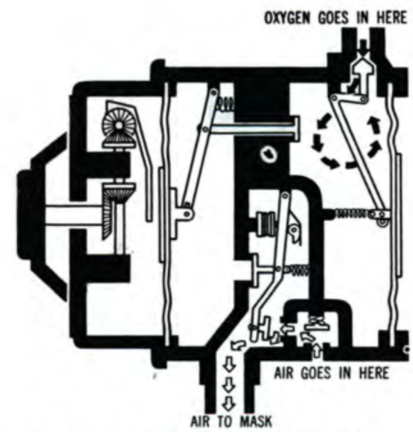


EXHALATION. The pressure inside the mask momentarily increases slightly above the inlet pressure, so that the main diaphragm and the compensating diaphragm are pushed down, permitting the exhaled breath to pass through the valve and the outlet.

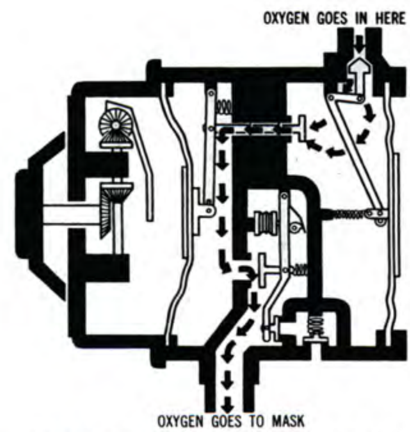


IF THESE INLET CHECK VALVES ARE NOT SET INTO PLACE PROPERLY, THE MASK WILL NOT WORK

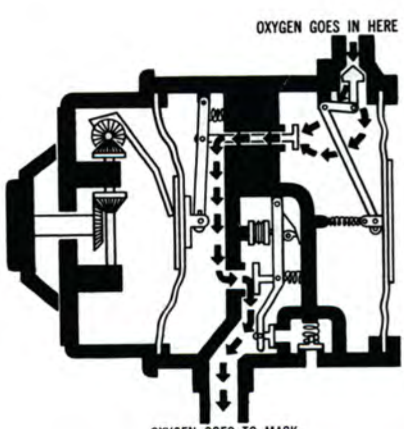
Figure 2–16. Components of Type MS–22001 Pressure Breathing Oxygen Mask.



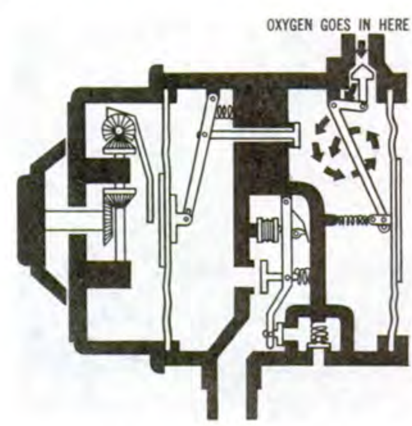
REGULATOR DURING INHALATION AT SEA LEVEL.
Oxygen valve is closed; air valve is open, and you breathe air only.



REGULATOR DURING INHALATION AT 34,000 FEET.
Air valve is closed; oxygen valve is open, and you breathe 100% oxygen.



REGULATOR DURING INHALATION WITH PRESSURE BREATHING. Spring presses down on diaphragm, opening de mand valve, and forcing oxygen into the mask under pressure



REGULATOR DURING EXHALATION WITH PRESSURE BREATHING. As you exhale, you momentarily raise the pressure, forcing the diaphragm up against the spring tension. The demand valve closes and no oxygen flows.

Figure 2–17. A–14 Manual Pressure Breathing, Diluter Demand Oxygen Regulator.

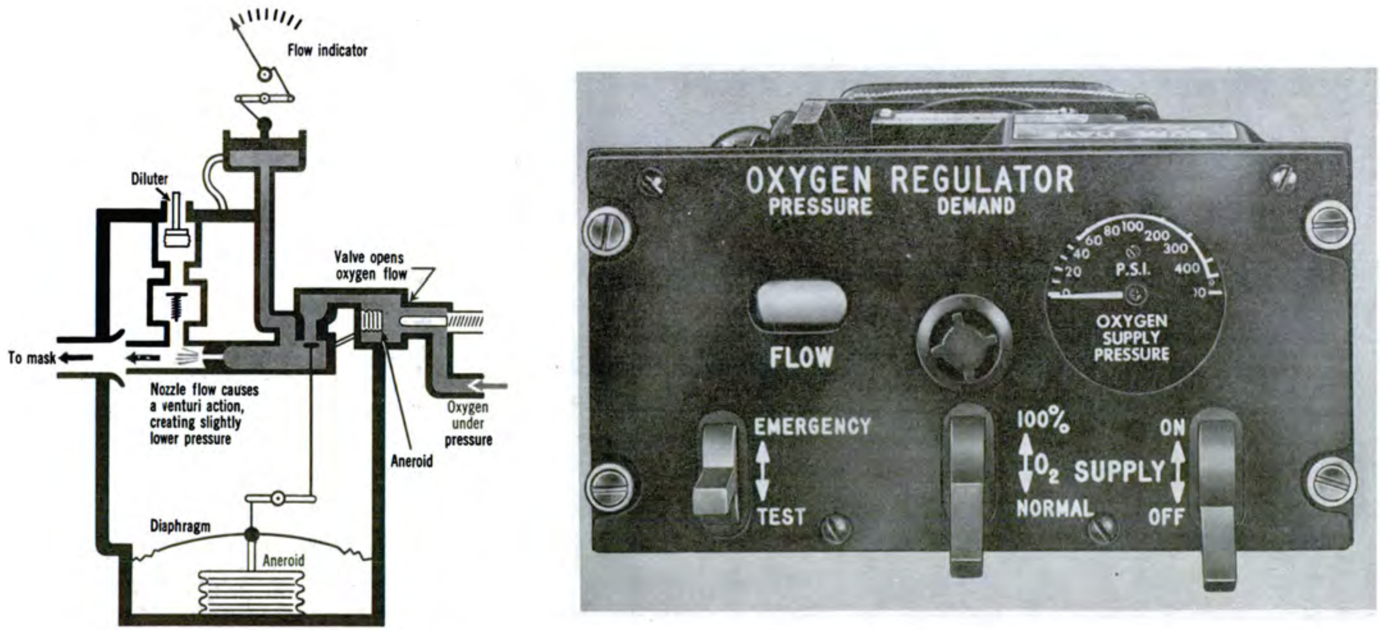


Figure 2–18. MD–1 Automatic Pressure Breathing, Diluter Demand Oxygen Regulator (Limited Standard).

seal is broken, there would be loss of oxygen to the outside atmosphere, but the slightly greater pressure within the mask would prevent ambient air from being drawn in during inspiration. This concept of "safety" pressure has been applied to standard pressure-demand oxygen systems and is used when the person is at an altitude between 30,000 and 40,000 feet.

Adjustment of the seal of the pressure-breathing mask upon the face makes it possible to increase its pressure-holding capacity and to permit breathing oxygen at pressures up to 30 mm Hg.

Basically, only two changes have been made in the demand-oxygen mask to convert it to a pressure-breathing system. They are shown in the illustration of the operation of the pressure-compensated valve (figure 2–16). The mask is molded with an inner flap (1) that tends to seal against the face when oxygen is delivered at positive pressures. In addition, it was necessary to alter the valve system because the standard demand-mask exhalation valve (3) opened at a very small positive pressure. A direct connection was made between the underside of the exhalation valve (4) and the incoming oxygen line (5). The pressure of the oxygen delivered by the regulator is, thus, effective in closing the exhalation valve.

To open the exhalation valve, then, it is necessary to exceed the pressure in the incoming oxygen line by exhaling with a greater force than that of the incoming oxygen. Check valves (2) over the oxygen inlet ports in the mask make it possible to develop the necessary exhalation pressure within the mask.

A spring applied to the diaphragm converts the standard demand regulator to the pressure-demand system (figure 2–17). The pressure-demand system may be activated automatically by an aneroid mechanism. The automatic type of control is essential for emergency situations arising in aircraft with operating ceilings up to 50,000 feet. Figure 2–18 illustrates a recent type of automatic regulator. For specific details on all current types of oxygen equipment, refer to the

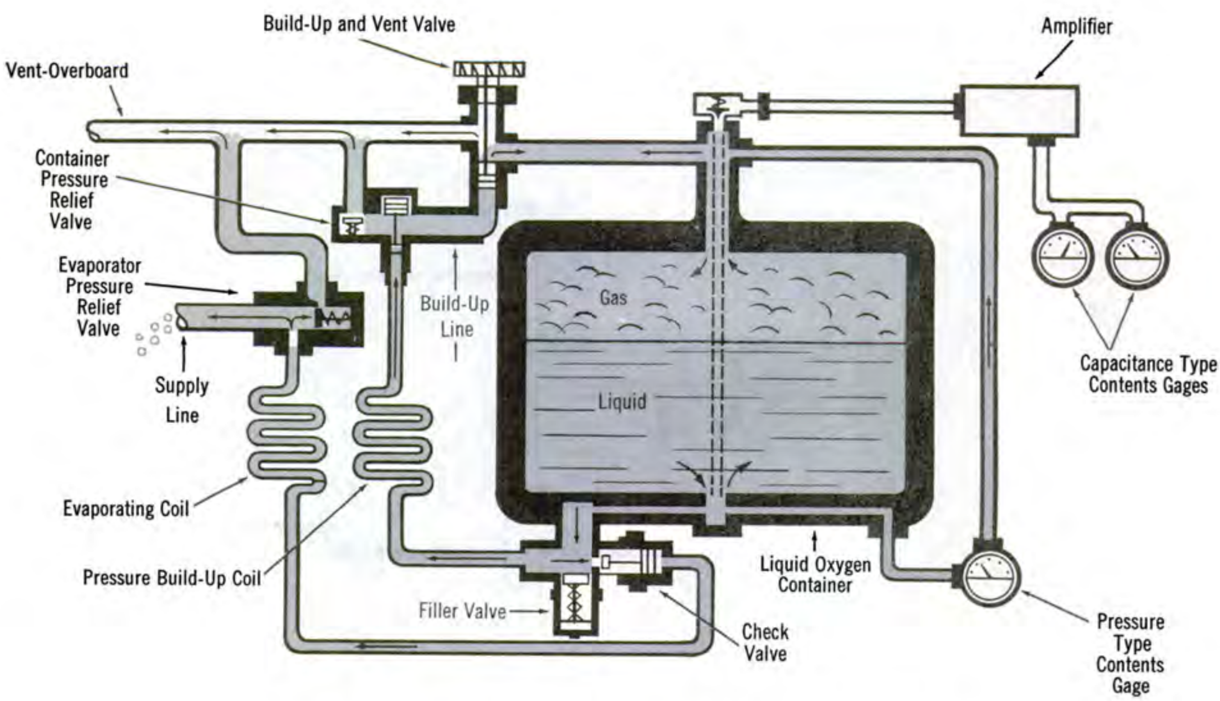


Figure 2–19. Schema of Liquid Oxygen System Components.

Capacity	5 liters
Operating Pressure	70 psi
Filling Pressure	20 psi
Filling Time	5 min
Build-Up Time	10 min
Weight (Empty)	14.0 lb.
Weight (Full)	26.5 lb.
Width (Overall)	12⅞ in.
Height (Overall)	9⅜ in.
Cubage (Maximum)	1,370 cu. in.

Figure 2–20. USAF Type A–3 Five-Liter Liquid Oxygen Converter.

current Technical Order listed in the references.

Liquid Oxygen Systems

The development of inflight refueling techniques and more effective aircraft and personal pressurization systems have extended the performance capabilities of current aircraft. Concurrent with these capabilities is an increased need for crew oxygen supplies due to the increased flight length.

This need was solved by the development of an entirely different, more complex oxygen system that used liquid oxygen (LOX) in place of gaseous oxygen. Even though there are disadvantages in this system, the LOX system more than offsets these disadvantages by storing large quantities of breathing oxygen in a compact, lightweight unit. Figure 2–19 shows the components of a LOX system and their relative positions. This schema is not typical of any particular aircraft installation, but is intended to indicate the operating characteristics of LOX systems in general. Figure 2–20 is a USAF Type A–3 five-liter liquid oxygen converter. One liter of liquid oxygen will provide approximately 800 liters of gaseous oxygen at normal sea level conditions. In comparison, a one-liter gaseous oxygen cylinder, pressurized to 450 psi, will provide only about 30 liters under the same conditions.

REFERENCES

Reader should insure the currency of listed references.

Armstrong, H. C., *Aerospace Medicine,* Chapters 8, 9, 10 & 13, The Williams and Wilkins Company, Baltimore (1961).

Boothby, W. M., *Handbook of Respiratory Physiology,* USAF School of Aviation Medicine (Project No. 21–2301–0003) (1954).

Comroe, J. L., et al., *The Lung,* Second Edition, Year Book Medical Publishers, Inc., Chicago (1962).

Gillies, J. A., *A Textbook of Aviation Physiology,* Pergamon Press, Oxford, England and Long Island City, New York (1965).

Luft, U. C., *Aviation Physiology. The Effects of Altitude.* In Fenn, W. O., and Rahn, H. (ed), Handbook of Physiology, Vol II, Chapter 44, Section 3: Respiration, American Physiological Society, Washington DC (1965).

Rahn, H. and Fenn, W., *A Graphical Analysis of the Respiratory Gas Exchange,* The American Physiological Society, Washington DC (1960).

Technical Order 15X–1–1, *Oxygen Equipment.*

School of Aerospace Medicine-Technical Documentary Report (SAM–TDR)–63–62.

School of Aerospace Medicine-Technical Documentary Report (SAM–TDR)–64–21.

Wright Air Development Center (WADC) Technical Report 58–352, Handbook of Respiration (Defense Documentation Center (DDC) No. AD–155823) (August 1958).

Chapter 3

EFFECTS OF DECREASED BAROMETRIC PRESSURE—DYSBARISM

Dysbarism is a general term that includes all the physiologic effects resulting from changes in barometric pressure with the exception of hypoxia. It is worth noting that this broad definition of dysbarism can include all of the disturbances within the body, which result from not only a reduction in the barometric pressure but from an increase in the barometric pressure as well. Thus, *dysbarism* is a broad term that can indicate most of the disorders that are experienced by underwater divers and caisson workers. Many of the disorders have the same etiology as those experienced by the aviator. The barometric pressure changes to which a diver or caisson worker can be subjected may be as great as several atmospheres (one atmosphere is equal to a pressure of 760 mm Hg or 14.7 psi), but the flier can be subjected only to a maximum barometric pressure change that cannot exceed 1 atmosphere. In comparing the diving and flying situations, the most serious disorders experienced by the diver are initiated by return to his normal pressure environment at sea level and can be treated only by returning again to the abnormally high pressure. On the other hand, the flier can experience similar disorders only at the abnormal environment of high altitude.

This chapter is primarily concerned with the disturbances that affect the flier as a result of reduced barometric pressures, either by exposure to high altitudes during actual flight or to simulated altitudes in a low pressure chamber. The principal disturbances that result from *increases* in the ambient pressure, such as the compression effects on the ears and sinuses during descent from altitude, are discussed in detail in chapter 6.

The syndrome resulting from a reduction in the barometric pressure is commonly referred to as *decompression sickness*, a term that includes the entire symptom complex that may develop. Other more limited terms that are sometimes used in a general sense with reference to decompression sickness are *aero-embolism* (gas bubbles in the blood vessels) and *aero-emphysema* (gas bubbles in the tissues). The specific term *ebullism* has recently been suggested to describe the unique medical syndrome with all the symptoms that can occur as a result of the boiling phenomenon at barometric pressures that are less than the vapor tension of body fluids.

The main symptoms of decompression sickness may be classified etiologically as:

a. Effects of evolved gases from body fluids and tissues resulting in such symptoms as bends, chokes, and neurological disorders (Henry's Law); and

b. Effects of expansion of trapped gases within the body resulting in such symptoms as abdominal gas pain and barodontalgia (Boyle's Law).

Etiology

The basic factors that produce this form of dysbarism at reduced barometric pressure are the expansion of trapped gas within the body cavities and the evolvement of gas bubbles in body tissues and fluids, particularly the evolvement of nitrogen that is in solution at normal barometric pressures.

On the reduction of the barometric pressure, gases within the body cavities tend to expand in accordance with Boyle's Law, and if the free escape of this expanding gas is grossly impeded or blocked, abnormally high gas pressures may develop, depending on the volume of trapped gas, the elastic characteristics of the surrounding organs and tissues, and the extent of the decompression itself. The gastrointestinal tract, the lungs, the middle ear, and cranial sinuses are the chief gas-containing organs and cavities but, ordinarily, the expanding air within the lungs, ears, and sinuses readily escapes during ascent to high altitudes, maintaining a reasonably normal equalization of pressure with the decreasing barometric pressure. On the other hand, the abdominal gas in the gastrointestinal tract often is unable to escape readily, resulting occasionally in a severe dysbaric symptom complex.

The initiation of the disorders resulting from *evolved gases* at high altitudes is best understood by considering first the characteristics and types of gases that are normally in solution in the body fluids and tissues and which are in dynamic equilibrium with the pulmonary alveolar gases, the surrounding barometric pressure, and the metabolic state of the body at sea level. The average adult body normally contains approximately one liter of dissolved "inert" nitrogen, together with a certain amount of metabolically active oxygen and carbon dioxide that are also in solution throughout the body, as well as the ever-present water vapor tension. Moreover, an additional important factor is that body fat and lipids contain about five times as much dissolved nitrogen (and oxygen) as the fat-free tissues and fluids. Thus, an obese person actually contains considerably more dissolved nitrogen per unit of body weight than a lean person. The amount of any gas dissolved in the body is dependent on the particular solubility characteristics of the gas in various types of body fluids (water, plasma, or fat) and is also directly proportional to the partial pressure of the gas with which the liquid is equilibrated in accordance with Henry's Law for dissolved gases. Since carbon dioxide is metabolically generated within the cells and tissues, it is excreted by diffusion in large quantities from the pulmonary blood through the lungs to the essentially carbon dioxide-free atmosphere. Oxygen diffuses continually in the opposite direction from the atmosphere to the blood and tissues. The metabolically inert nitrogen, on the other hand, remains throughout the entire body in a relatively steady state of equilibrium with the nitrogen tension in the lungs and atmosphere. As the barometric pressure decreases with ascent to high altitudes, this equilibrium for nitrogen is drastically upset. The body tissues and fluids become supersaturated, and nitrogen tends to be evolved from solution as gaseous bubbles which initiate the major symptoms of this form of dysbarism. Presumably, the aching and painful symptoms of bends are produced by such bubbles located interstitially in the connective tissue about the bones, joints, and muscles where the limited capillary vascularity is inadequate for quickly carrying away the excessive accumulation of gas. The symptoms of chokes are believed to be caused by the accumulation of such bubbles intravascularly in the pulmonary capillary bed, leading to the typical rapid shallow breathing and, as has been measured in animals, a pulmonary hypertension.

It should be pointed out here that, although nitrogen is the most likely gas for maintaining a bubble, it is not clear as to which gas first initiates the submicroscopic bubble and establishes the conditions for bubble growth to a size capable of producing the symptoms of dysbarism. Water vapor, together with carbon dioxide and oxygen, may first form a relatively unstable gas nucleus into which all gases in solution can further diffuse in proportion to their gas tensions in the liquid. *For example*, carbon dioxide can enter or leave a bubble 50 times more readily than nitrogen and, of course, water vapor will be present the instant that conditions for a bubble are established.

The *evolved bubble theory* is the most convincing and attractive for explaining many of the signs and symptoms of decompression sickness, although it has not as yet been completely proven with absolute certainty. The fact, however, that denitrogenation before exposure to low barometric pressures provides considerable prophylactic protection against dysbarism, indicates that nitrogen plays a basic role in the etiology of this syndrome. Moreover, after the onset of decompression sickness, recompression usually brings prompt and dramatic relief. On the other hand, the bubble theory fails to explain the delayed occurrence of some of the most serious neurocirculatory manifestations after recompression to ground level. Also, the fact that the incidence of aviator's decompression sickness appears to be higher in the morning than in the afternoon and evening, is difficult to explain on the bubble theory alone. There are strong indications that several other important unknown factors are also involved in the etiology and progress of this disease. Other theories that have been suggested to help explain these apparent discrepancies in the bubble theory include the *vasospasm theory*, based on the observations of Knisely, and the *fat emboli theory*, stemming from Haymaker's postmortem observations and the work of Rait, which indicate a disruption of fatty tissues with involvement of congenital cardiovascular defects and/or liver and nutritional considerations.

It has been shown that the incidence of dysbarism increases with the rate of ascent, the peak altitude, duration of exposure to altitude, exercise and muscular activity, and cold. The incidence decreases with increasing time of denitrogenation.

Individual susceptibility varies widely from person to person and within a given individual from time to time. Age is an important consideration with an increase in susceptibility for older age groups. Whether this is due primarily to age itself or to the fact that older people are often more obese is not clear. There is a good correlation with the incidence of dysbarism and obesity, probably due to the fact that the obese individual has considerably more nitrogen to eliminate than the lean person. Tissue vascularity and blood circulation are also important factors, the efficiency of which often decreases with both age and obesity. On the other hand, physical fitness and previously healed injuries to bones and joints within limits encountered in personnel on flying status, do not appear to influence susceptibility significantly. However, susceptibility is extraordinarily increased by exercise while at altitude. Exercise not only increases the incidence and severity of the symptoms at altitude, but causes the symptoms to occur sooner than when at rest. With vigorous exercise at altitudes of about 38,000 feet, 100% of the population can be expected to develop bends within 30 minutes. In addition, exercise lowers the threshold altitude for the occurrence of bends symptoms. Ordinarily, the evolved gas symptoms of severe dysbarism do not occur below the critical threshold altitude of 30,000 feet, but symptoms may be induced at altitudes as low as 22,000 feet by strenuous exercise. However, even with a person at rest, symptoms have been reported occasionally in this altitude range.

Symptoms

According to a decompression reaction study on 62,160 trainees between 1943 and 1945, the five most prevalent painful reactions that occurred during altitude chamber flights were bends (13%), aerotitis (7.86%), abdominal distresses (4%), sinus pain (1.17%), and barodontalgia. Vasomotor instability, chokes, hypoxia, visual disturbances, and hyperventilation all totaled less than 1%.

Bends are the most frequent manifestation of decompression sickness and, at altitude, are characterized by a deep pain in the bones, joints, and muscles of the extremities, including the hips and shoulders. The pain is often diffuse and poorly localized, and is felt as a boring, gnawing, or aching pain that can progress in intensity to the point of becoming intolerable and incapacitating. The onset of pain can be fulminating, but more often, it is mild and gradual. The pain can be transitory, intermittent or steady, can occur in one joint, or it can progress to several locations in the extremities with different degrees of intensity. No general rule can be stated with regard to onset, duration, intensity, location, or the length of time at altitude before bends symptoms are first noticed, if at all, when at rest. The knees and shoulders are the locations most often involved. All degrees of bends can lead to general circulatory reactions.

Chokes usually occur later in the course of exposure to altitude than do bends and are characterized by the following: A substernal burning sensation which is referred to the deep respiratory passages; nonproductive cough arising deep within the chest; and aggravation of both of the above manifestations by a deep breath, accompanied by a sense of suffocation and apprehension. The onset is almost inevitably progressive, leading to severe distress within a few minutes. General circulatory reactions are more common with chokes than with bends. Chokes at altitude should be regarded as a dangerous symptom that can lead quickly to the most severe and grave consequences, and prompt descent or recompression should be initiated without delay.

The paresthesias frequently associated with dysbarism are generally of little consequence. Objective skin manifestations, which may occur with or without paresthesias, are seen with some frequency and take the form of either intracutaneous blebs, subcutaneous emphysema, or a mottled skin lesion. The mottled skin lesion, presenting as irregular areas of erythema adjoining areas of cyanotic pallor, is considered a serious sign since it may be associated with chokes and neurocirculatory instability or collapse. Ordinarily, prompt termination of the flight results in rapid disappearance of these symptoms with, however, a residual tenderness over the involved area, becoming maximal several hours postflight and sometimes persisting for 2 or 3 days.

Neurological symptoms occur rather infrequently. The most common type is a transitory visual defect consisting of homonymous scotoma or even hemianopsia, followed by headache, which closely resembles migraine. More rarely, transitory hemiplegia, monoplegia, aphasia, and disorientation occur. The neurological reactions differ from the other symptoms by their tendency to occur shortly after flight as well as during flight.

Abdominal pain is a common symptom resulting from trapped expanding gas. In spite of its different etiology, it occurs at about the same altitude as the other symptoms caused by evolved gas. It makes its appearance typically early in the course of the flight and may progress from a simple feeling of distention to severe, cramp-like pain. When severe, it may lead to circulatory reactions.

Barodontalgia is a painful condition of the jaws and teeth, experienced during or shortly after exposure to lowered barometric pressure in flight or in a low pressure chamber. The causative factors of this painful condition have never been fully explained. In some instances, it has been associated with subclinical pathological conditions that, ordinarily, are not bothersome to nonflying personnel. It is probable that barodontalgia does not occur with a healthy pulp. Over 9% of the fighter pilots of one command reported this type of pain at some time during their flying career.

Predisposing factors in toothache at altitude are large, deep-seated, silver fillings without underlying base materials or insulators, and various stages of inflammation or degeneration of the plup. Toothache at altitude is most likely caused by an underlying lesion in the pulp which, in time, would cause the same symptoms without decompression.

In general, the pain is worse with greater and more rapid decompression and is relieved usually by recompression. The precise "altitude of incidence," severity, and duration of pain will vary with the individual and the type of lesion in the pulp. Occasionally, pain may first appear on descent from altitude or on recompression. Available information indicates that, in some instances, pulpitis of varying degrees may be found together with "spaces" in the pulp.

When several teeth are suspected of causing pain, those with recent amalgam fillings are more probably responsible. Testing with ice may reproduce the pain. A tooth is to be suspected if it continues to hurt after removal of the ice. A tooth with an open cavity will not be affected by altitude even though the pulp is diseased.

The character of the pain varies in intensity, duration, and location. In many cases, its severity will render the flier militarily ineffective during the periods of painful attacks. The pain may be made to recur by reproducing the same flight conditions in the altitude chamber or when actual flight conditions prevail. Barodontalgia, unlike painful disturbances in the region of the ear and sinus, is more prevalent during ascent and at altitudes. In some cases, however, it has occurred on descent or on the ground following a level flight.

Complications and Sequelae

The most serious complication of dysbarism is a type of neurogenic peripheral circulatory failure or primary shock, consisting of one or all of the following manifestations: intense pallor, profuse sweating, faintness and dizziness, nausea, vomiting, and loss of consciousness. These circulatory reactions are usually initiated at altitudes at which the primary symptoms of bends, chokes or gas pains are most severe, and recede rapidly as the primary symptoms are relieved by descent from altitude. In some instances, the reaction persists after reaching ground level and may develop into the hematogenic form of peripheral circulatory failure or secondary shock.

Delayed circulatory reactions also may occur within several hours after return to ground level. After an apparent asymptomatic interval, these delayed reactions may present the typical picture of secondary shock with weak, thready pulse, hypotension, and intense hemoconcentration. A few fatal cases of this type have been encountered. Neurological symptoms sometimes may accompany such delayed shock. Hemiplegia and coma have resulted and, in some instances, permanent residuals.

Treatment

The only effective prophylactic measure against decompression sickness is denitrogenation before ascent to altitude. By breathing air containing a reduced pressure of nitrogen, the latter is removed from the body. The most rapid denitrogenation is accomplished by breathing pure oxygen. Above 20,000 feet, the effectiveness of denitrogenation is greatly reduced. Breathing pure oxygen at ground level for 15 minutes will reduce the incidence of bends and chokes at 38,000 feet by approximately 50%. Dysbarism is rare in current operational flying as long as the cabin altitude remains below 30,000 feet.

The prophylaxis of gas pains is a more difficult problem. The only reliable guide is to eliminate, as far as possible, conditions or procedures that cause abdominal distress at ground level since symptoms of these conditions are likely to be aggravated by altitude. Figures are given in cases per 100 persons exposed.

DISTRIBUTION OF ALTITUDE CHAMBER REACTIONS

Symptom	*Air Force CY 1964*	*Air Force CY 1965*
Aerotitis	8.73	8.66
Aerosinusitis	1.59	1.86
Barodontalgia	0.23	0.30
Abdominal Gas Pain	1.96	1.85
Bends	0.31	0.30
Chokes	0.003	0.008
Neurological	0.002	0.00
Other (skin, etc.)	0.78	0.67
TOTAL	13.605	13.648

NOTE: 52,113 aircrew members trained in 1964 and 49,603 in 1965.

A failure of a reactor to respond to recompression must be viewed as a serious event. Cerebral, visceral or cardiovascular gaseous embolization at the arteriolar and precapillary levels initiates focal ischemia. Recompression exerts a positive mechanical effect on bubbles to cause a decrease in their size, but recompression cannot be expected to influence directly existing irreversibly damaged areas.

Recent successes in therapy have established the value of chamber compression to more than one atmosphere in the treatment of severe cases of altitude dysbarism. The few severe cases that have thus far been treated have shown good recovery at 3 to 6 atmospheres absolute pressure. Several therapeutic compression chambers are located at geographically strategic sites within the Air Force. The treatment of severe cases of altitude dysbarism by this means is the current method of choice. If the patient is transported by air, cabin pressure must be maintained at or near sea level.

Involvement of motor and sensory functions in either spinal cord or cortex, visceral involvement, or direct cardiovascular involvement produces a remarkable disorder commonly termed "neurocirculatory collapse." In its mildest form, the disorder is seen as a self-limiting, transitory vasomotor instability, indistinguishable from a syncopal reaction. In its severest form, the disorder presents widespread neurological involvement and acute hypovolemic shock, with progressive deterioration to a fatal termination. Within this framework, neurocirculatory collapse may be seen as an almost uncomplicated neurological disorder, or primarily as a shock-like syndrome. Generally, both neurological and circulatory involvements are seen.

Treatment is largely empirical and expectant. Immediate recompression to ground level is required. Compression to more than one atmosphere has merit but must be considered in the light of the availability of such a specialized treatment facility. Complete bed rest must be emphasized, even in the cases of mild vasomotor instability where the patient may be asymptomatic at rest, but demonstrates postural hypotension on sitting or standing. All cases which demonstrate postural hypotension for more than an hour or two should be hospitalized and observed for at least 24 hours. Depending on the nature and severity of the disorder, supplemental breathing oxygen should be given. The use of an oxygen-carbon dioxide mixture not to exceed 3% carbon dioxide is probably useful.

For cases that are recognized as hypovolemic shock, vigorous supportive treatment is extremely important. The use of plasma expanders is necessary. These should be given in amounts sufficient to maintain an adequate hourly urine output; 30 to 50 ml/hour suggests successful replacement. The hematocrit and the vital signs (blood pressure, pulse) are important indices of successful treatment as well.

Each case is a peculiar individual event and the Flight Surgeon must be prepared to treat acute pulmonary edema, acute congestive failure, or even a cardiac arrhythmia, all of which are accompaniments of this remarkable and serious complication of evolved gas dysbarism.

Rapid Decompression

The development of the pressurized cabin in aircraft has introduced a new potential hazard for the flier in the event that this cabin pressurization is accidentally and suddenly lost, either as the result of enemy action or the spontaneous rupture of the cabin structure. It is thus necessary to consider carefully the range of human tolerance to such sudden decrease in the barometric pressure. First, it is important to distinguish between the possible effects that can occur *during* the rapid decompression itself, such as being physically injured or actually blown out of the aircraft through the opening, and the effects of the low barometric pressure that is encountered *after* decompression, such as hypoxia and dysbarism and, in addition, if above 63,000 feet, the vaporization of body fluids if adequate protective equipment is not available immediately.

The two main factors that influence the severity of a decompression are: a. The rate and time of the decompression; b. the absolute change in the barometric pressure. The faster the decompression and the greater the change in pressure, the more severe can be the effects. In turn, the basic factors that determine the rate and the severity of a decompression are: (1) The volume of the pressurized compartment; (2) the size of the opening in the cabin; (3) the pressure differential (^{P}cabin — ^{P}ambient); (4) the pressure ratio (^{P}cabin/^{P}ambient); and (5) the flight altitude at which the decompression takes place.

The relationship of the volume of the cabin to the size of the opening and the *pressure ratio* determines the time of a decompression (not the pressure differential). The larger the volume and the smaller the opening, the slower will be a decompression and, also, the larger the pressure ratio, the slower the decompression. Furthermore, the higher the flight altitude for any given pressure differential, the longer it will be before a cabin decompresses completely; the higher the altitude the larger the pressure ratio. (A thorough analysis of decompression times and the above relationships are in the *General Theory of Rapid Decompression* by Haber and Clamann, listed in the references.)

Figure 3–1 illustrates the theoretical expansion of body gases during decompressions up to altitudes of 60,000 feet. This relative gas expansion (RGE), however, has certain analytical limitations since it does not take into account the *volume* of the expanding gas.

The physiological effects of explosive decompression are produced by rapid expansion of gases within body cavities; the degree of decompression that can be withstood safely is determined either by the extent or the rate of expansion. When the expansion is slow, the body gases tend to escape readily

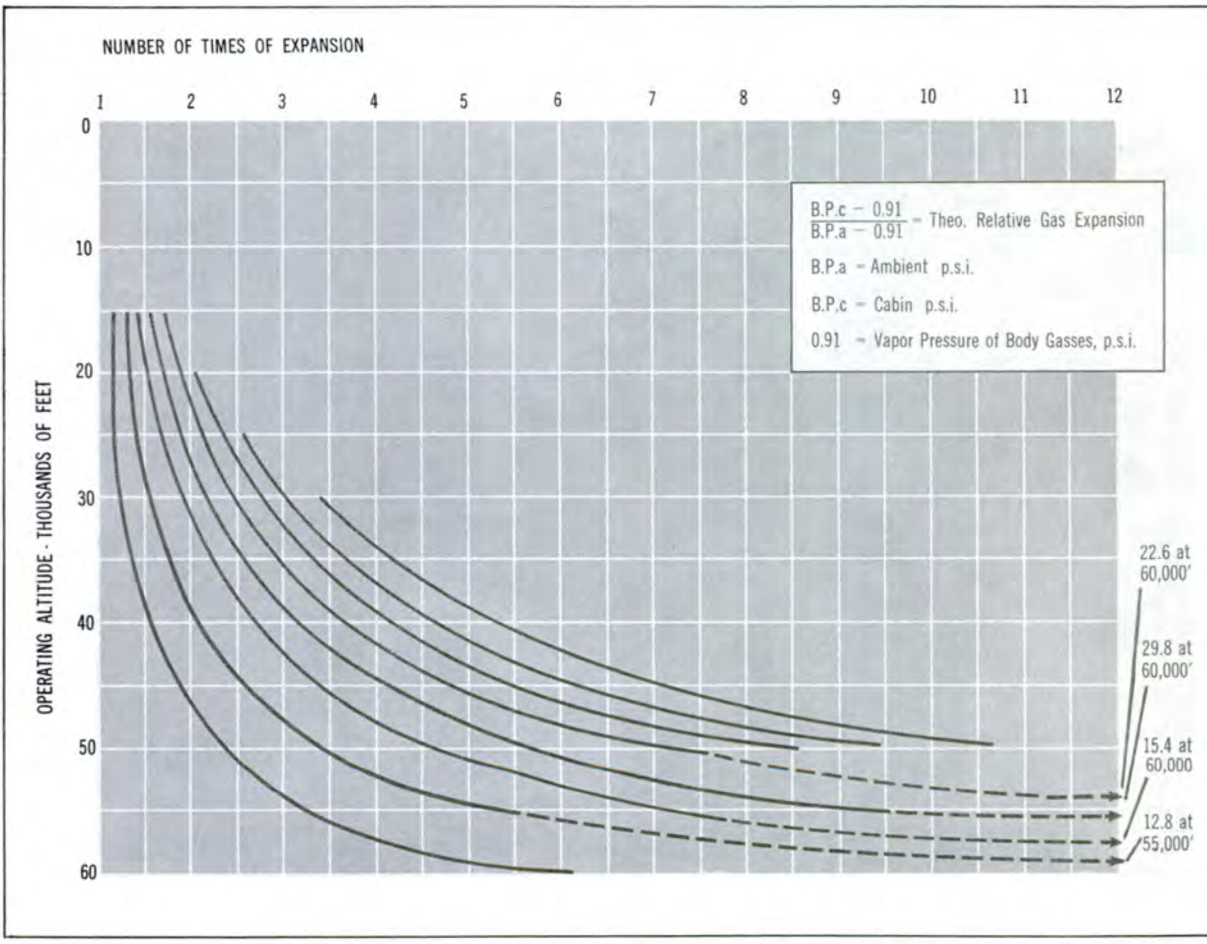


Figure 3–1. Theoretical Expansion of Internal Body Gases Upon Equalization of Cabin Differentials From 1.0 Through 8.0 psi.

or become redistributed before dangerous pressures are built up. When the decompression and the degree of expansion are slight, the lungs and hollow viscera can distend safely to make room for the expanded gas.

Expanding gas is normally expelled from the lungs with little resistance through the open airways and trachea, but if the flow of escaping gas is blocked, physiological stretching of the distended lung tissue commences when the gas volume is double the vital capacity. In decompressions with expansion of gases to several times their original volume at an extremely rapid rate, the response of the lungs is the limiting factor in tolerance of normal subjects to explosive

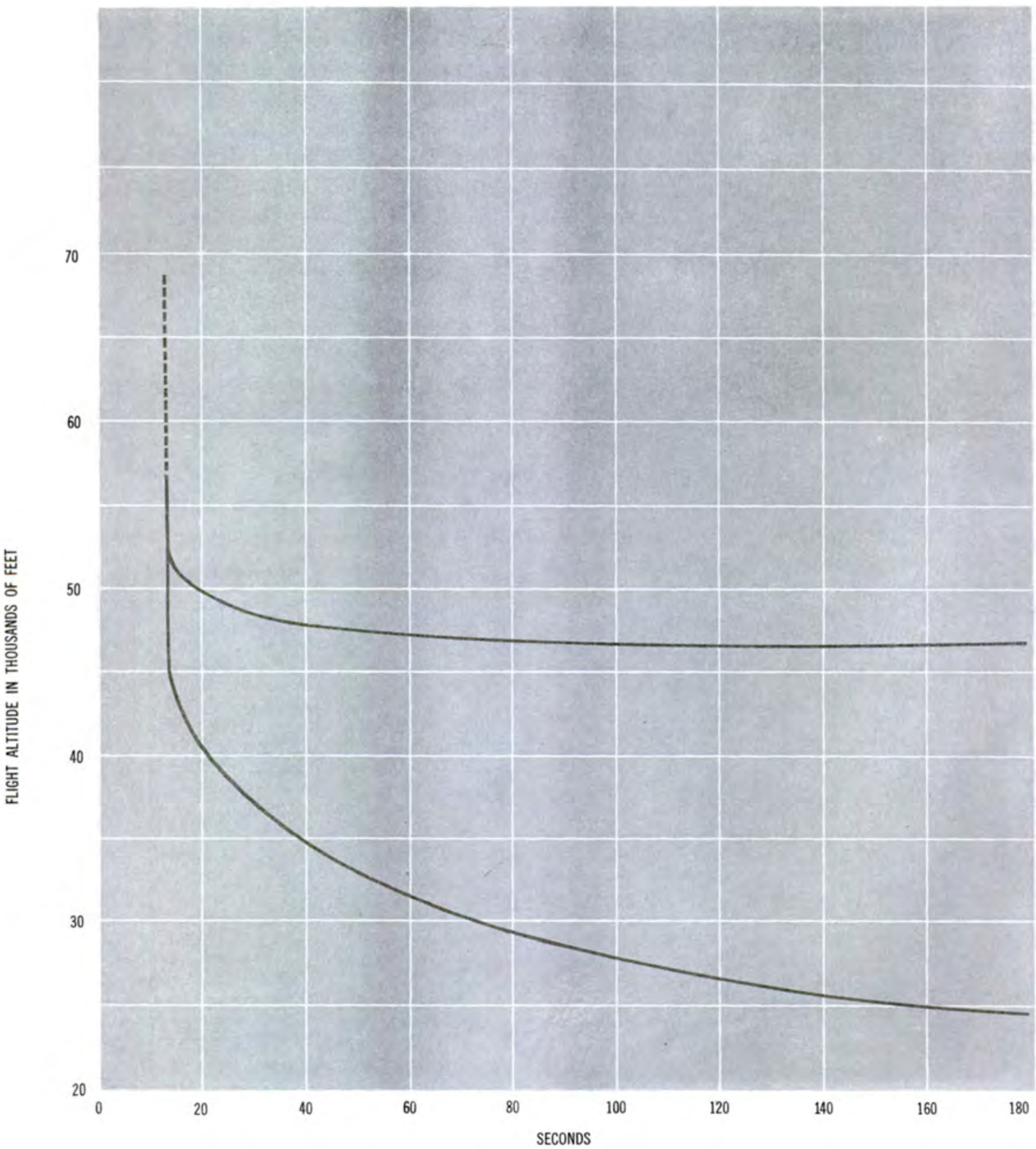


Figure 3–2. Flight Altitude in Thousands of Feet.

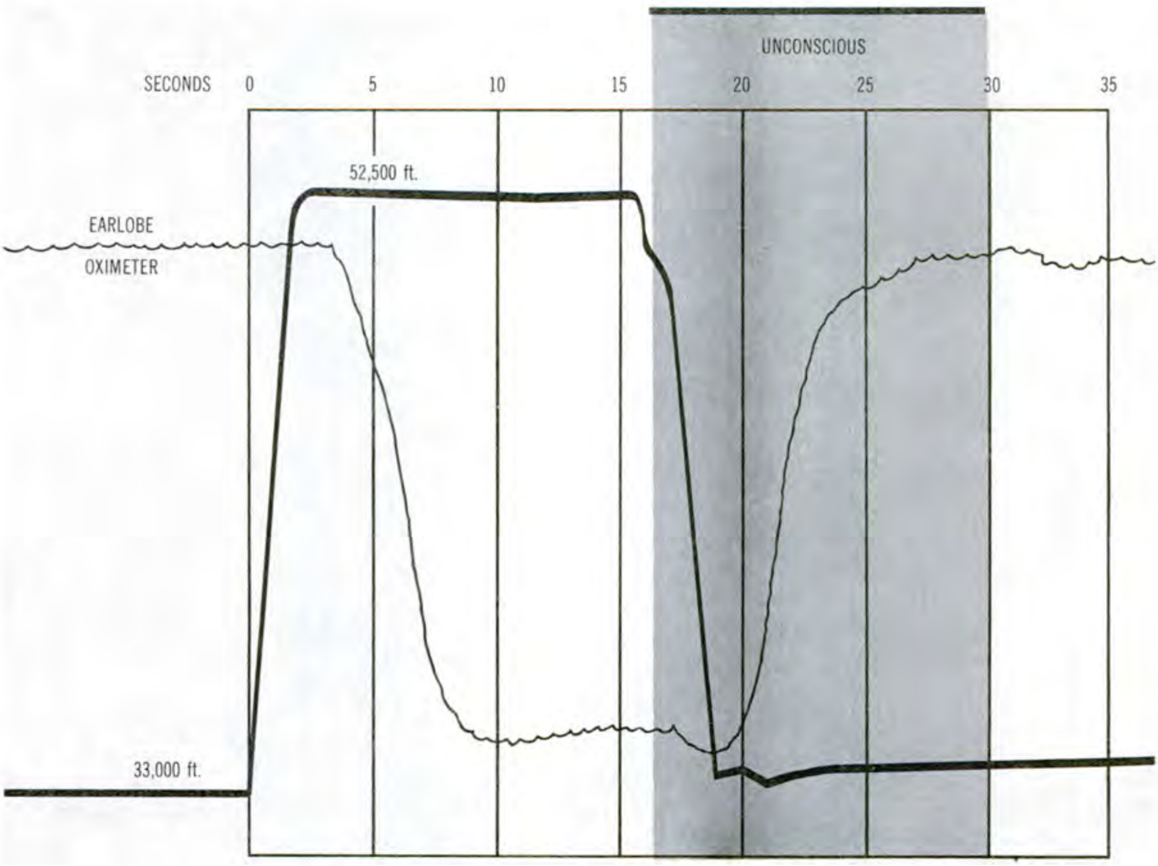


Figure 3–3. Minimum Free Interval in Which Hypoxic Manifestations Are Latent.

decompression. Critically high pressures will occur in the lungs if the glottis happens to be closed at the moment of decompression, either due to voluntary breath-holding, or, inadvertently, as in the act of swallowing. Traumatic aero-mediastinum and aero-embolism into the systemic circulation due to pulmonary lesions have been observed in a few rare instances, with one fatality.

The expansion of gases within the gastro-intestinal tract causes distention which may give rise to an occasional twinge. Persons with excessive abdominal gas, however, may suffer more severe pain. No aural discomfort has been observed during rapid decompression, possibly because the eustachian tubes are blown open immediately and remain open during the change in pressure.

If a flier must remain at high altitude following a sudden decompression, the symptoms of dysbarism may be expected to occur if adequate denitrogenation was not accomplished prior to the decompression. Experimental work with humans has revealed that extraordinarily rapid rates of decompression can be tolerated with little difficulty. Rapid decompressions from 8,000 to 35,000 feet in less than 0.1 second have been tolerated.

While the immediate mechanical effects of rapid decompression on occupants of a pressurized cabin will seldom be incapacitating, the menace of subsequent hypoxia becomes more formidable with increasing operational altitudes. The time of consciousness after loss of cabin pressure (10,000 feet or less) while breathing air is indicated in the lower curve of figure 3–2. The upper curve represents the time available on decompression to altitudes above 45,000 feet, using oxygen from a simulated cabin altitude of 33,000 feet (or less).

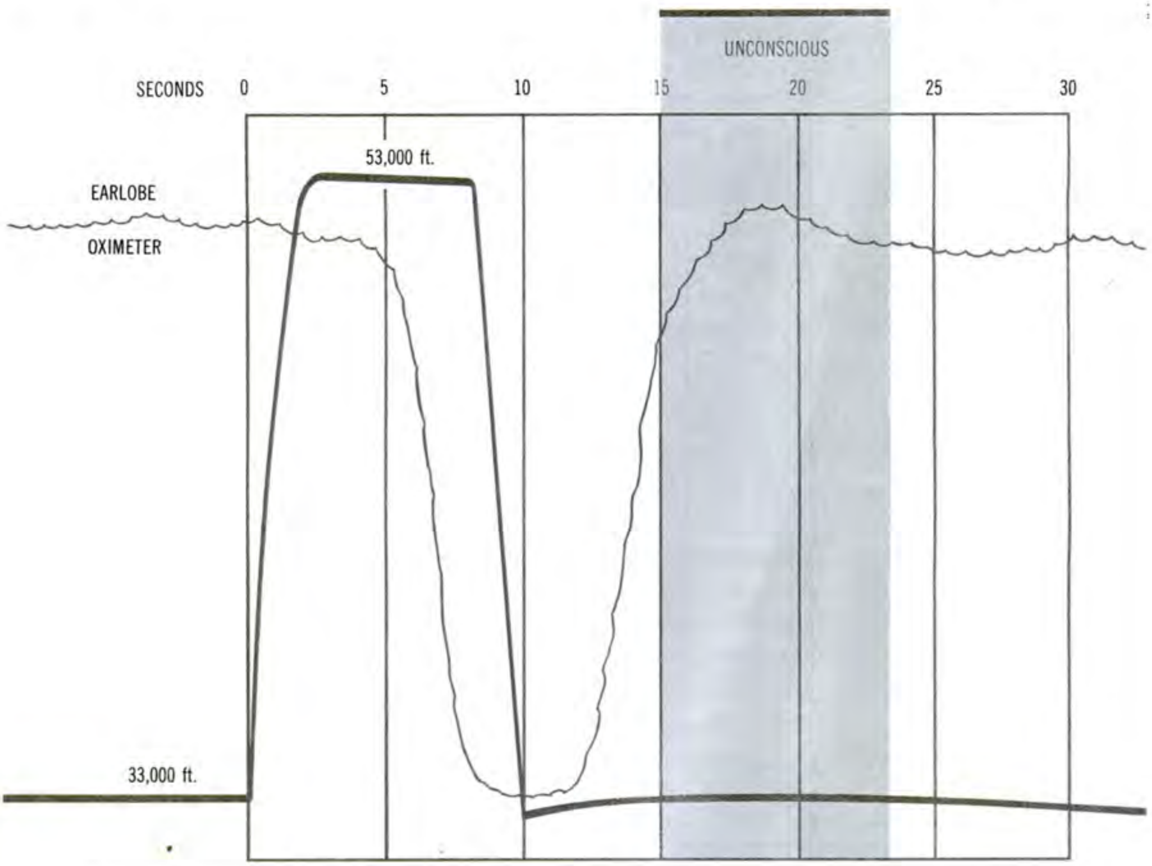


Figure 3–4. Loss of Consciousness After Rapid Decompression Is Terminated Before the Latent Period of Hypoxia Has Elapsed.

The advantage gained by breathing oxygen is most convincing up to 45,000 feet, but becomes less and less significant at higher altitudes. Both curves converge at 52,000 feet where the time of consciousness is the same, regardless of whether air or oxygen is breathed. It is not implied that the use of oxygen equipment is of no value in such an emergency. On the contrary, the chances of survival by recompression, pressure breathing, or free fall will be infinitely better when oxygen is available throughout.

As evident from figure 3–2, the time of consciousness reaches a minimum of approximately 15 seconds at 45,000 feet, breathing *air*. At 52,000 feet, the same minimum exists when *oxygen* is used. Figure 3–3 demonstrates this latent period that can be accounted for partly by the circulation time of blood from the lungs to the brain and by the tissue oxygen reserves.

If the exposure to altitude after rapid decompression is terminated before the latent period of hypoxia has lapsed (figure 3–4), loss of consciousness will ensue, nevertheless, at the time when the blood, which has been deprived of its oxygen, takes effect on the brain. This may take place even after adequate oxygen pressure has been regained in the lungs by recompression. Only when the exposure to a critical altitude (above 45,000 feet with air, above 52,000 feet with oxygen) does not exceed 5 to 6 seconds can temporary loss of consciousness be avoided by protective devices designed to become effective within that time.

For a limited approximation in predicting the possible stress on the human body during a rapid decompression, the following two formulas have been found to be useful in predicting the probable danger limit of this stress to the human body. These two formulas are:

$$\text{RGE (calculated)} = \frac{Pc - 0.91}{Pa - 0.91}$$

$$\text{RGE (maximum)} = 2.1 + \frac{3.79\ Vc}{A}\sqrt{\frac{Pc - Pa}{Pa}}$$

where: RGE = relative gas expansion; A = total cross-sectional area in square inches of the opening in the pressurized compartment (in predicting A, the largest Plexiglas opening is suggested); Vc = volume of the pressurized compartment in cubic feet; Pa = outside atmospheric pressure in pounds per square inch; and Pc = inside compartment pressure in pounds per square inch.

If RGE (calculated) is greater than RGE (maximum), danger exists; if RGE (maximum) is greater than RGE (calculated), the operating conditions may be considered safe.

REFERENCES

The reader should insure the currency of listed references.

Adler, H. F., *Neurocirculatory Collapse at Altitude*, USAF School of Aviation Medicine, Special Project Report (June 1950).

Armstrong, Harry G., *Aerospace Medicine*, Chapters 12 & 13, The Williams and Wilkins Co., Baltimore (1961).

Benzinger, Th., *Explosive Decompression*, German Aviation Medicine in World War II, pages 395–408, Washington DC (1950).

Comfort, E. C. and Wilson, J. W., *Some Factors Affecting Time Consciousness at High Altitudes*, Air Force Technical Report No. 5970 (November 1949).

Fulton, J. F., *Decompression Sickness, Caisson Sickness, Diver's and Flier's Bends and Related Syndromes*, W. B. Saunders Co., Philadelphia (1957).

Gillies, J. A., *A Textbook of Aviation Physiology*, Chapters 5, 6, 7 & 8, Pergamon Press, Inc., New York (1965).

Haber, F. and Clamann, H. G., *A General Theory of Rapid Decompression*, Project No. 21–1201–0008, Report No. 3, USAF School of Aviation Medicine (1953).

Ha'l, F. G., *Factors Affecting Consciousness Time at Altitude, Part II*, Air Force Technical Report No. 6009 (September 1950).

Haymaker, W. and Johnston, A. D., *Pathology of Decompression Sickness, a Comparison of the Lesions in Airmen With Those in Caisson Workers and Divers*, Military Medicine 117:285 (1955).

Knisely, M. H. and Block, E. H., *Microscopic Observations of Intravascular Agglutination of Red Cells and Consequent Studying of the Blood in Human Diseases*, Anatomical Record, Volume 82:34 (1942).

Luft, U. C., Clamann, H. G., and Opitz, E., *The Latency of Hypoxia on Exposure to Altitudes Above 50,000 Feet*, Journal of Aviation Medicine 22:117 (April 1951).

Rait, W. L., *The Etiology of Postdecompression Sickness in Aircrewmen*, US Armed Forces Medical Journal 10:790 (1959).

Ward, J. E., *The True Nature of the Boiling of Body Fluids in Space*, Journal of Aviation Medicine 27:429 (1956).

Chapter 4

EFFECTS OF ACCELERATIVE FORCES

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

BASIC PRINCIPLES OF AIRCRAFT MOTION

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

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

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

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

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

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

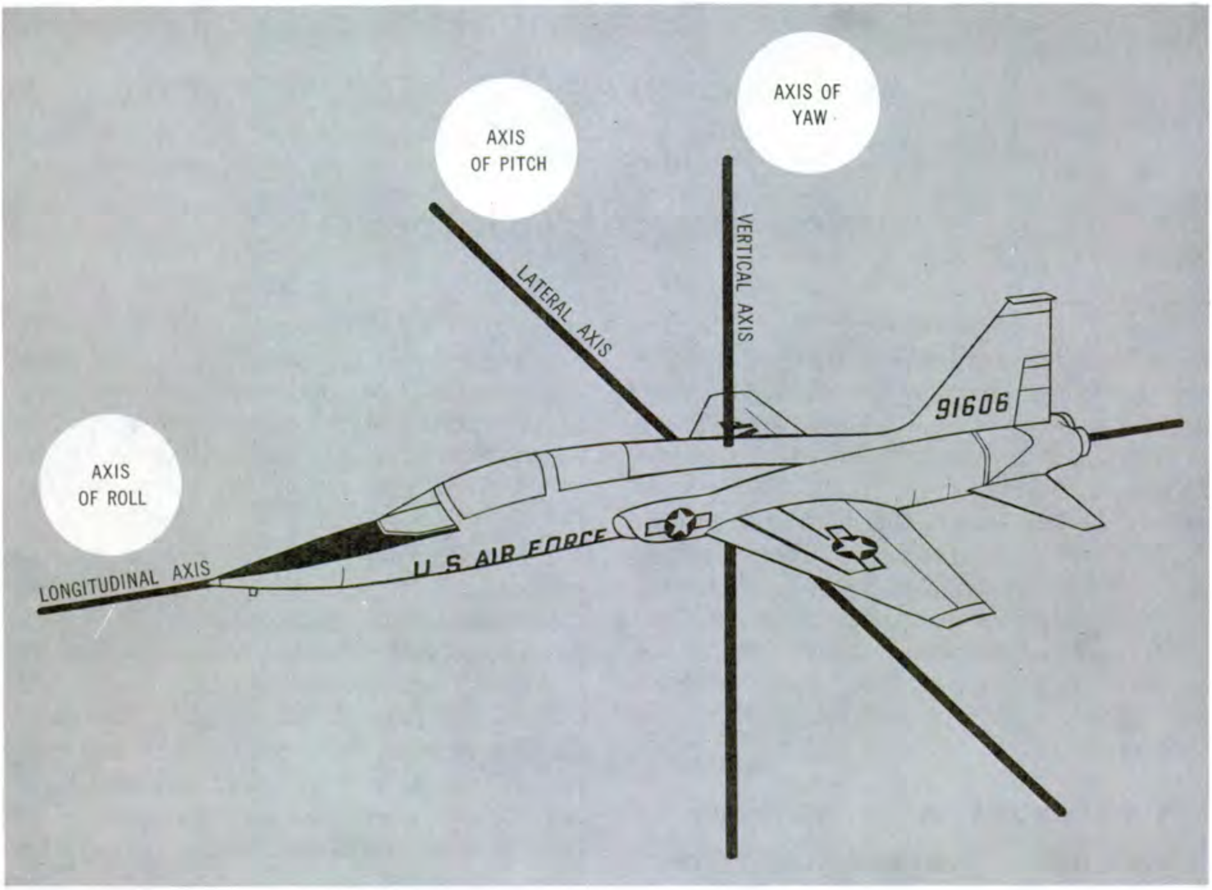


Figure 4–1. Axes of the Aircraft.

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

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

ACCELERATIVE FORCES AS APPLIED TO AVIATION

Newton's Laws of Motion

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

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

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

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

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

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

Acceleration. Newton's second law deals with the force involved in overcoming inertia. This force is called acceleration and is defined as change of velocity per unit of time. It covers changing direction and changing speed, including starting from rest (acceleration) and stopping (deceleration). Newton's second law states: *When a body is acted upon by a constant force, its resulting acceleration is inversely proportional to the mass of the body and is directly proportional to the applied force.* This may be expressed mathematically by the equation: $a = \frac{F}{M}$ or $F = Ma$, where F stands for the number of pounds of applied force, M for the mass, and a for the acceleration in feet/sec². *Acceleration* has already been defined as change in velocity per unit of time. *Force* is considered to be any push or pull that tends to produce or prevent motion.

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

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

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

G Forces

The most commonly known acceleration is the acceleration of falling bodies due to the force of gravity. This acceleration is 32.2 feet/sec² and the force producing it is called 1G. Therefore, an acceleration of 640 feet/sec² is 20 Gs, since 640 feet/sec² is an acceleration twenty times as great as the acceleration gravity. Force and acceleration are proportional ($F = Ma$) and a force which produces an acceleration of 640 feet/sec² is twenty times as great as the force of gravity.

Types of Acceleration

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

$a = V^2/r$ where:

V = airspeed and r = radius of turn

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

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

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

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

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

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

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

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

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

Factors Influencing the Effects of Acceleration

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

a. The degree (intensity) of the force,

b. The time (duration) of application,

c. The rate of application,

d. The area and site over which the force is applied (*i.e.* to the body), and

e. The direction of the accelerative force with respect to the long axis of the body.

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

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

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

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

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

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

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

Direction of G Force Action

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

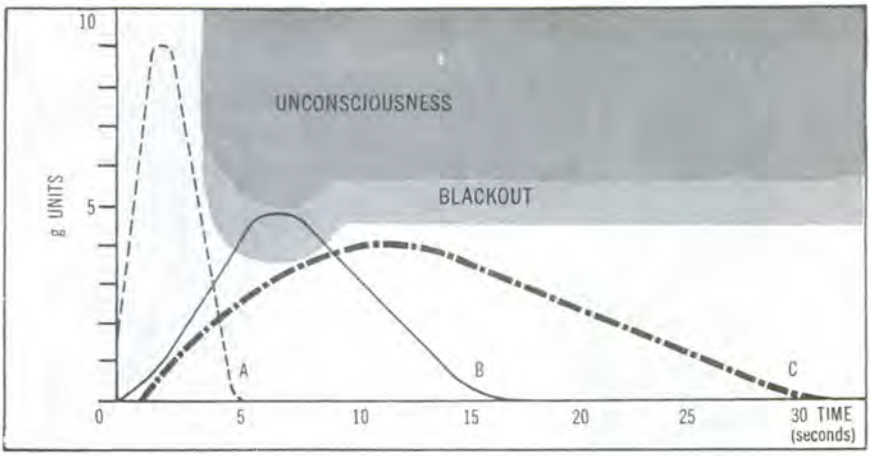


Figure 4–2. Relationship of Positive G Tolerance to Duration of G Forces.

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

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

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

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

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

EFFECTS OF G FORCES

Effects of Positive G

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

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

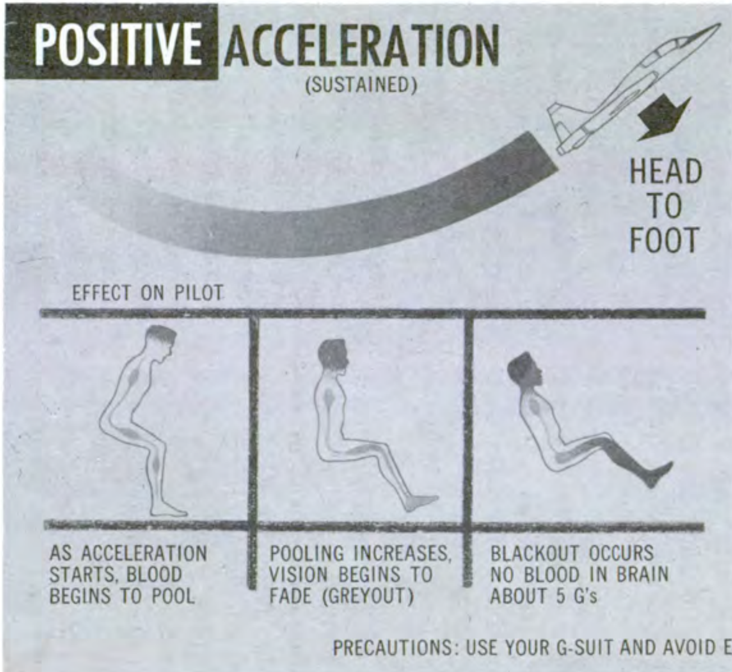


Figure 4–3.

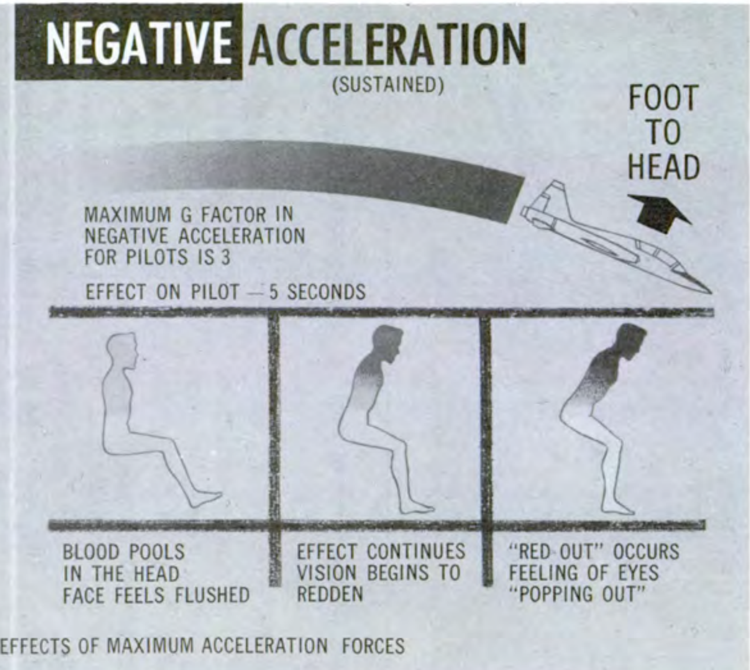


Figure 4–4.

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

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

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

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

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

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

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

Effects of Negative G

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

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

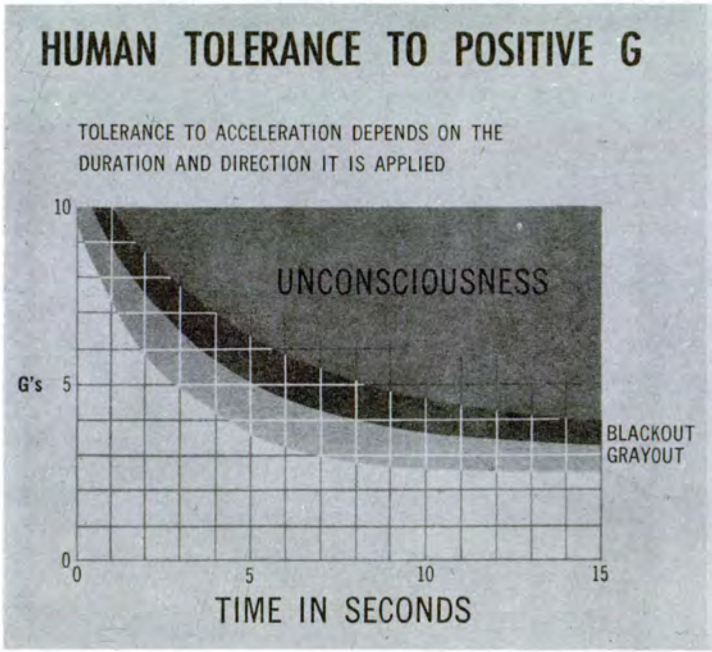


Figure 4–5. Human Tolerance to Positive Acceleration.

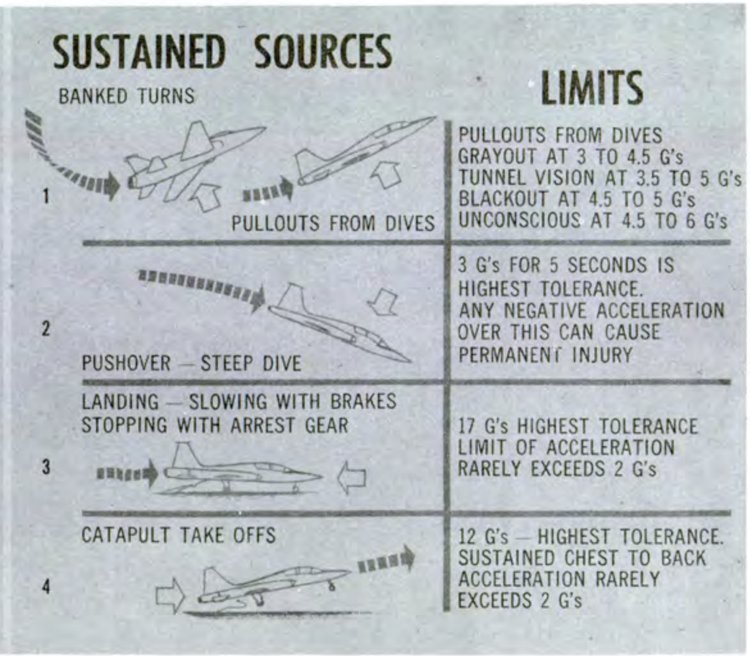


Figure 4–6. Limits of Sustained Gs.

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

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

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

Effects of Transverse G

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

G TOLERANCE

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

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

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

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

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

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

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

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

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

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

Figure 4–7. Effects of Positive G.

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

Devices to Protect Against G Forces

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

M–1 Maneuver

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

Anti-G Suits

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

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

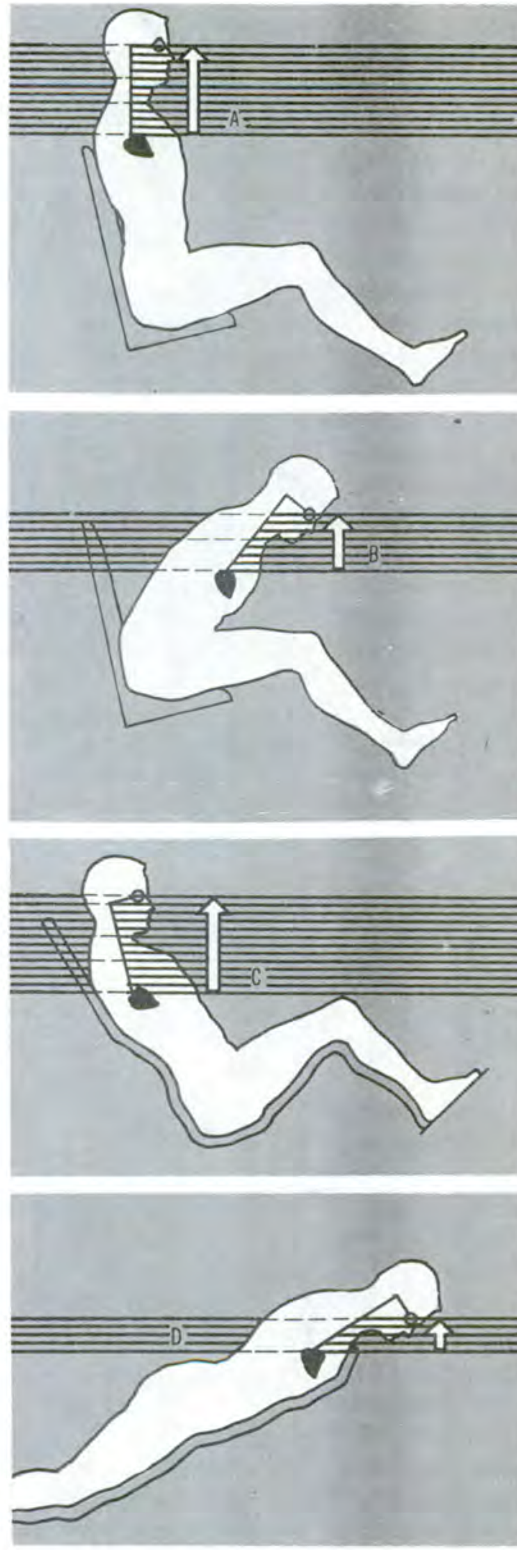


Figure 4–8. Effect of Position in Heart to Head Distance.

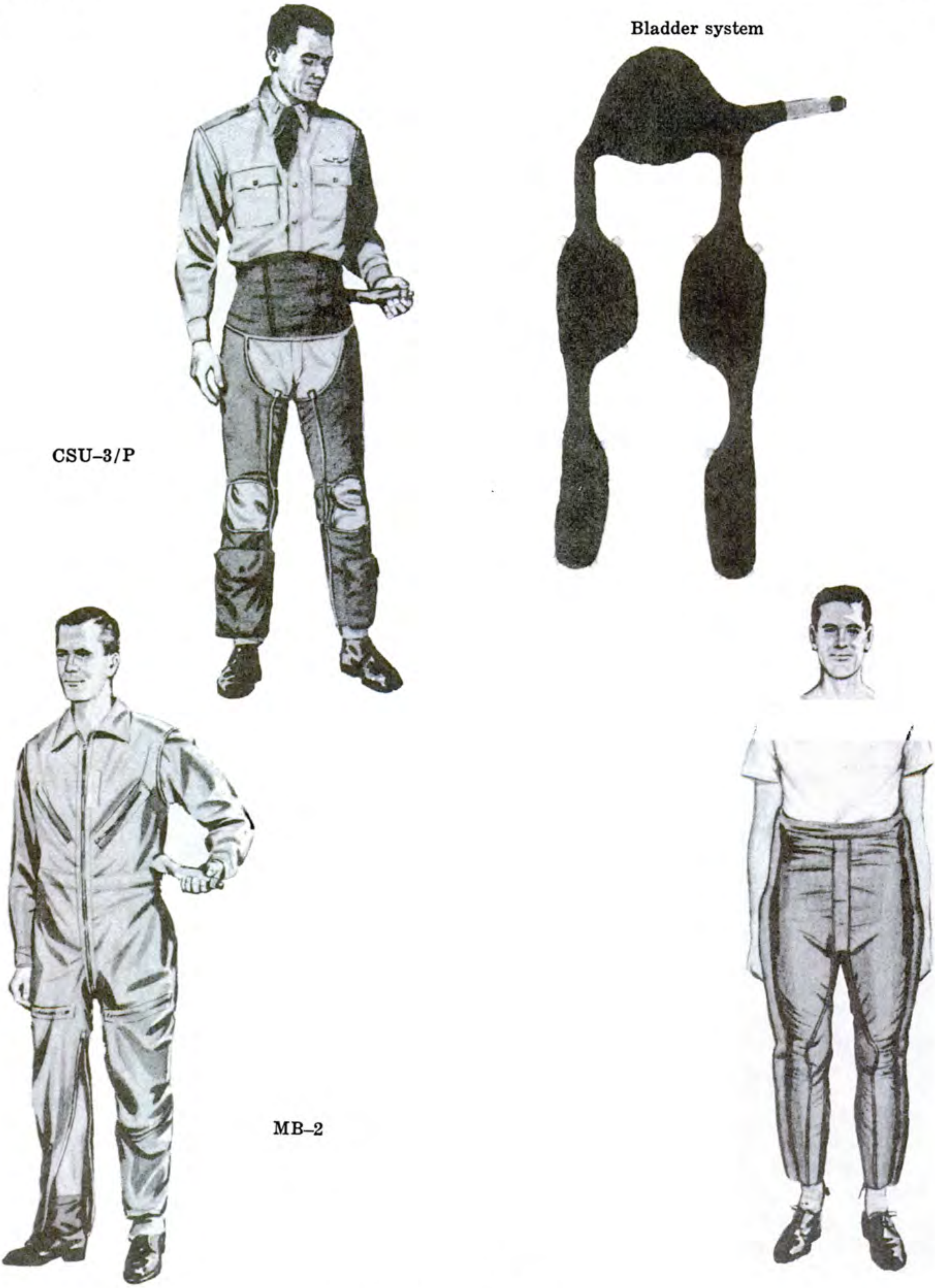


Figure 4-9. Anti-G Suits.

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

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

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

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

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

SENSORY RESPONSES TO ACCELERATIVE FORCES

Sensory Modalities

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

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

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

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

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

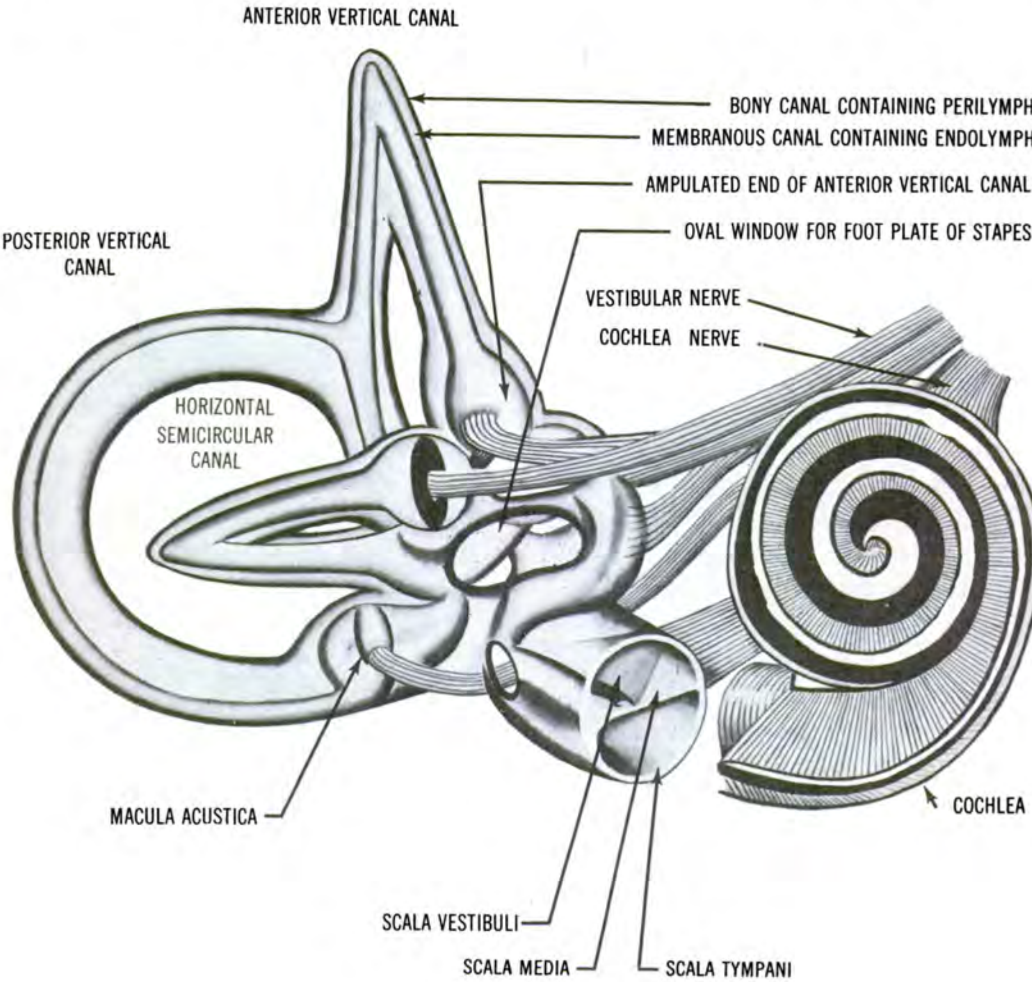


Figure 4-10. The Inner Ear.

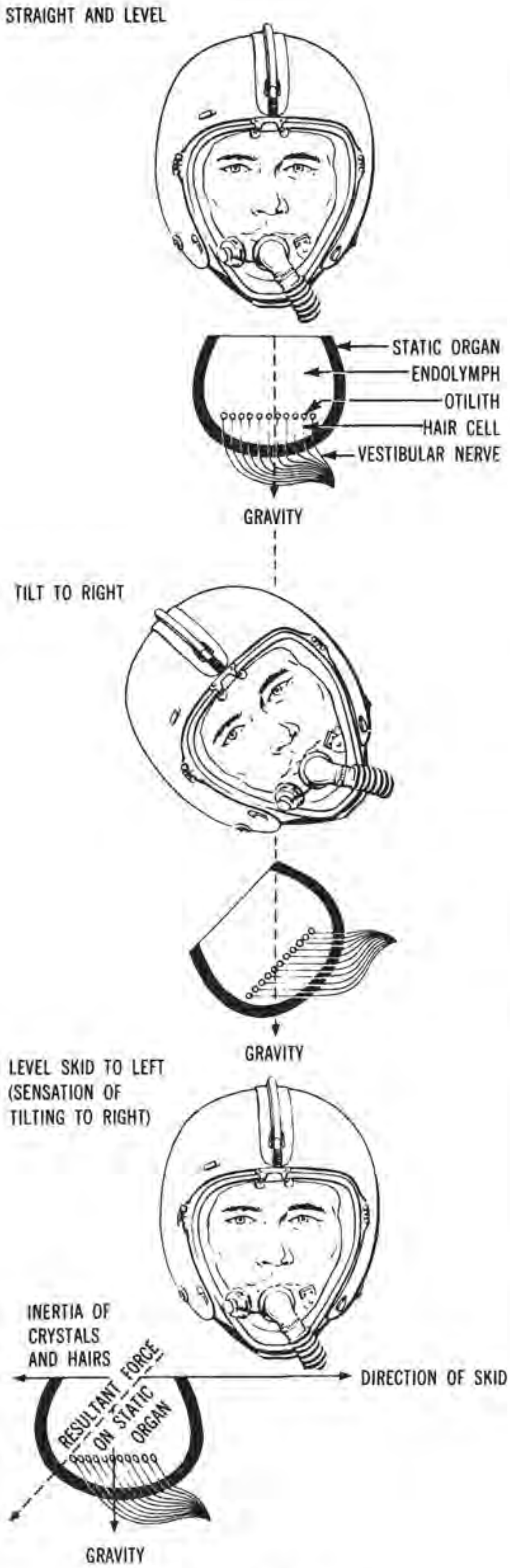
glass is stopped, the water will continue to rotate.

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

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

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

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



Head Position.

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

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

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

Vestibular Responses

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

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

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

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

Proprioception

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

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

ILLUSIONS OF FLYING

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

Optical Illusion

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

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

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

Illusion of Turning

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SPATIAL DISORIENTATION

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

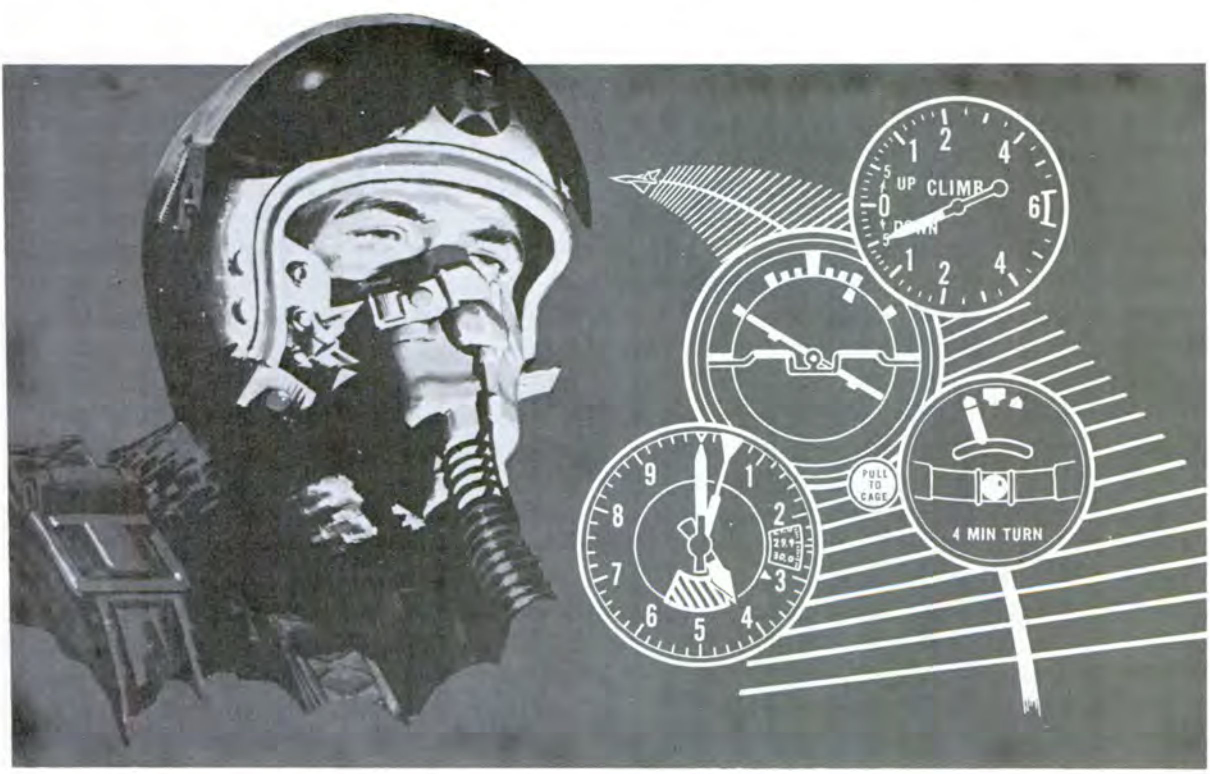


Figure 4–13. When Spatial Disorientation Occurs, Flight Should be Accomplished With Reference to Visual Interpretation of the Instruments.

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

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

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

Sensations from the semicircular canals may be erroneous for two basic reasons. First, the canals are stimulated by angular acceleration which displaces the cupula. This produces a sensation of rotation only as long as the cupula is displaced. If the acceleration is constant, or is decreased, the sensation of rotation stops, or seems to reverse. At any rate, the impression the pilot receives bears little or no relation to the actual direction or magnitude of rotation.

The second reason for inappropriate cues from the semicircular canals is that the cupula acts as a damped pendulum system, and has a slow recovery from a displaced position. This produces an after-sensation of rotation after the acceleration ceases. In addition, the otolith organs produce positional cue errors because they are stimulated by both gravity and rectilinear acceleration without being able to distinguish between forces due to gravity and those caused by other accelerations.

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

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

While the incidence of spatial disorientation appears to be highest among student pilots during training, many experienced pilots have stated that their first encounter with a serious disorientation incident occurred after entering operational flying. Jet flying does show a definite propensity to produce disorientation. Severe vertigo experiences are approximately five times more frequent among jet pilots than among nonjet pilots when balanced statistically for equal hours flown in each type aircraft.

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

Since the basic factor involved in the production of disorientation is a normal physiological response to the unavoidable accelerations of flight, there is little one can do to eliminate the cause. Indoctrination, training, and practice are, therefore, basic requirements which cannot be circumvented. It should be remembered that vision is the only sense which can be relied upon regardless of the frame of reference, be it the earth, another aircraft, or flight instruments.

AIRSICKNESS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ABRUPT ACCELERATIONS

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

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

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

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

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

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

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

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

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

Development of Escape Systems

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

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

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

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

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

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

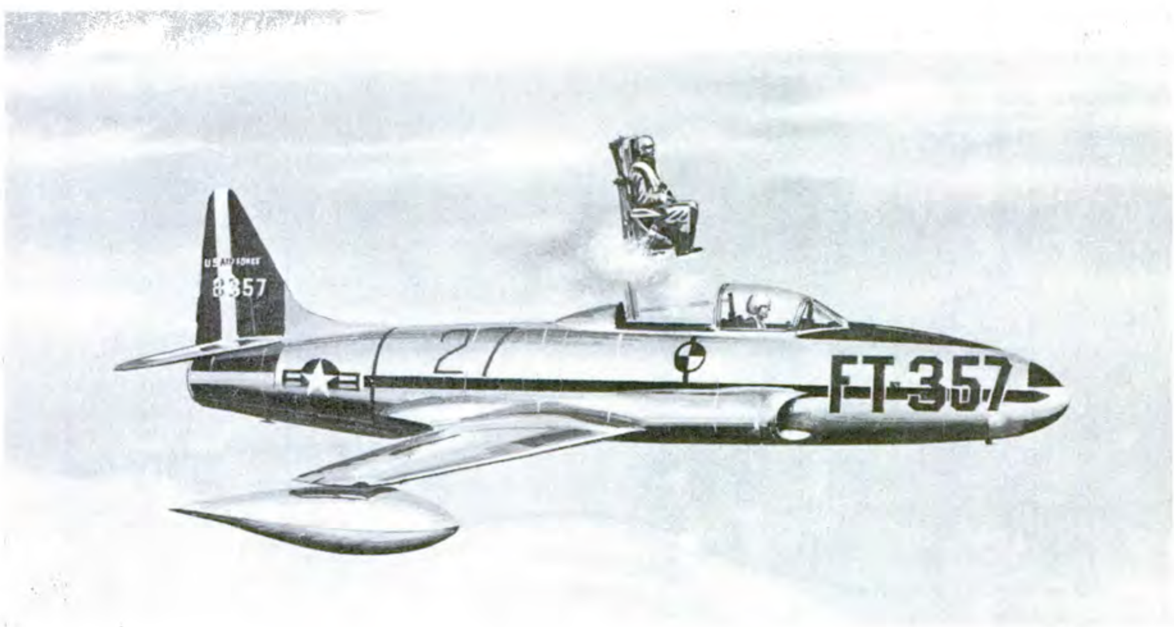
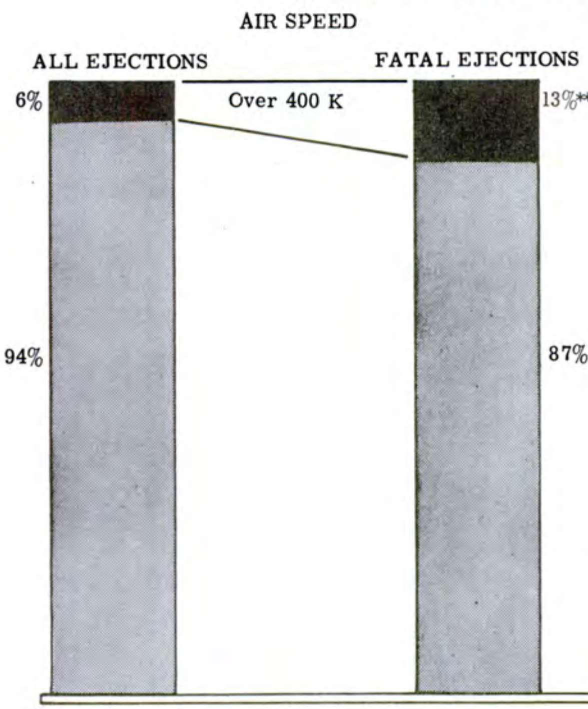
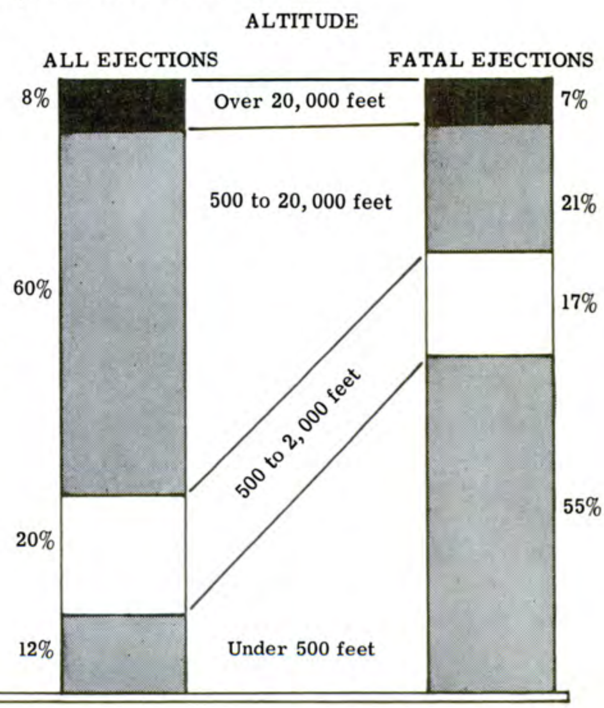


Figure 4–14. Experimental Ejection To Test the System.



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

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



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

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

Figure 4–17. Correct Position for Ejection.

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

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

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

Ejection

An adequate ejection mechanism must:

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

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

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

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

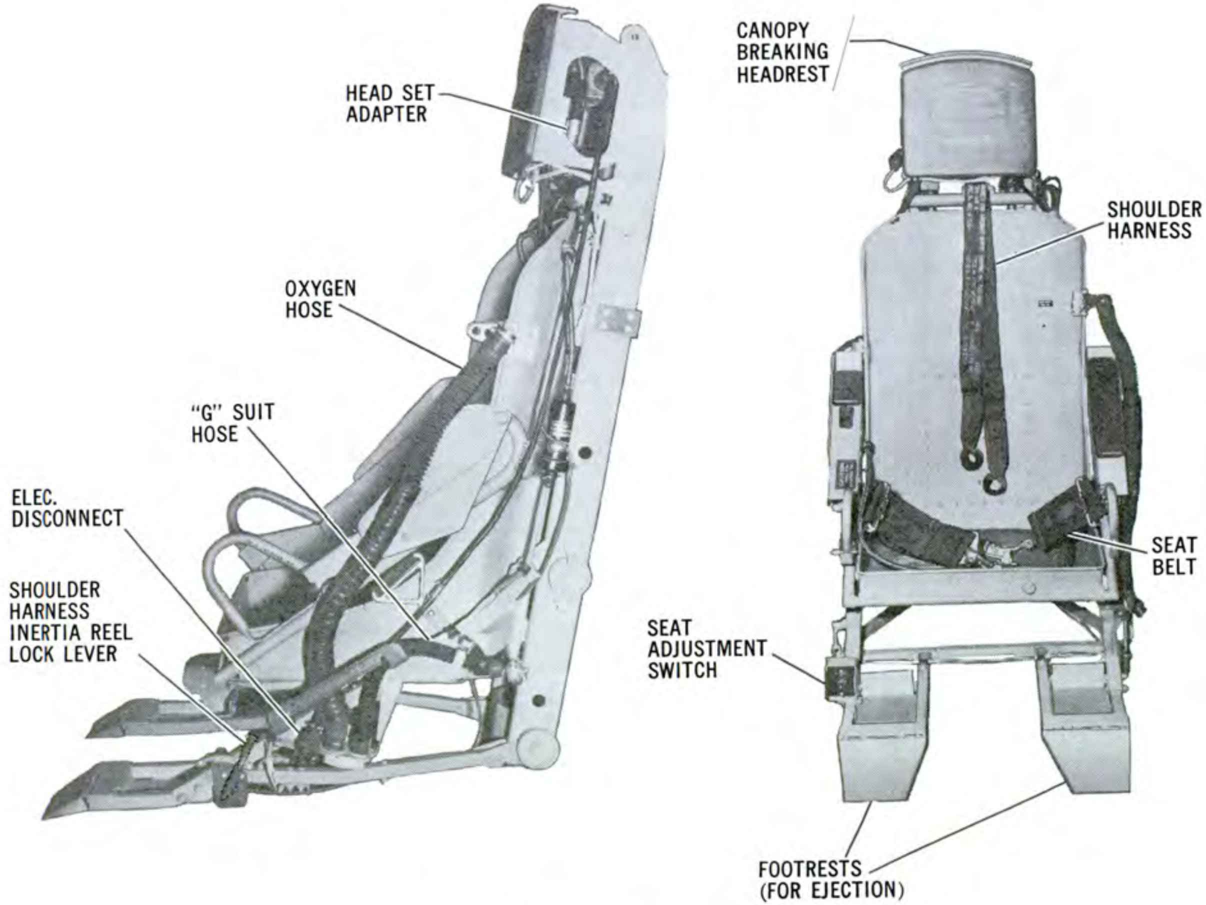


Figure 4–18. Ejection Seat.

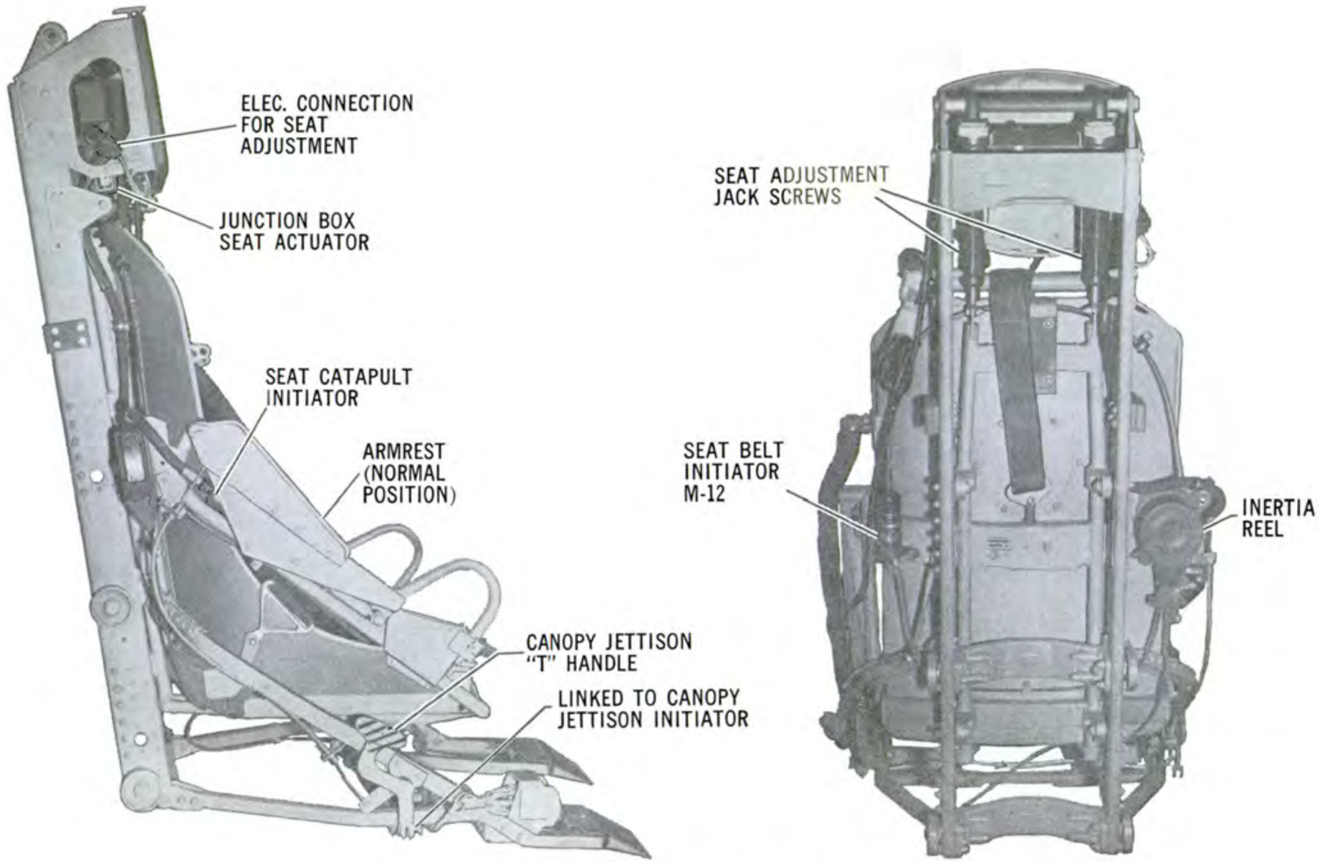


Figure 4–18. Continued.

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

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

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

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

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

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

Deceleration

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

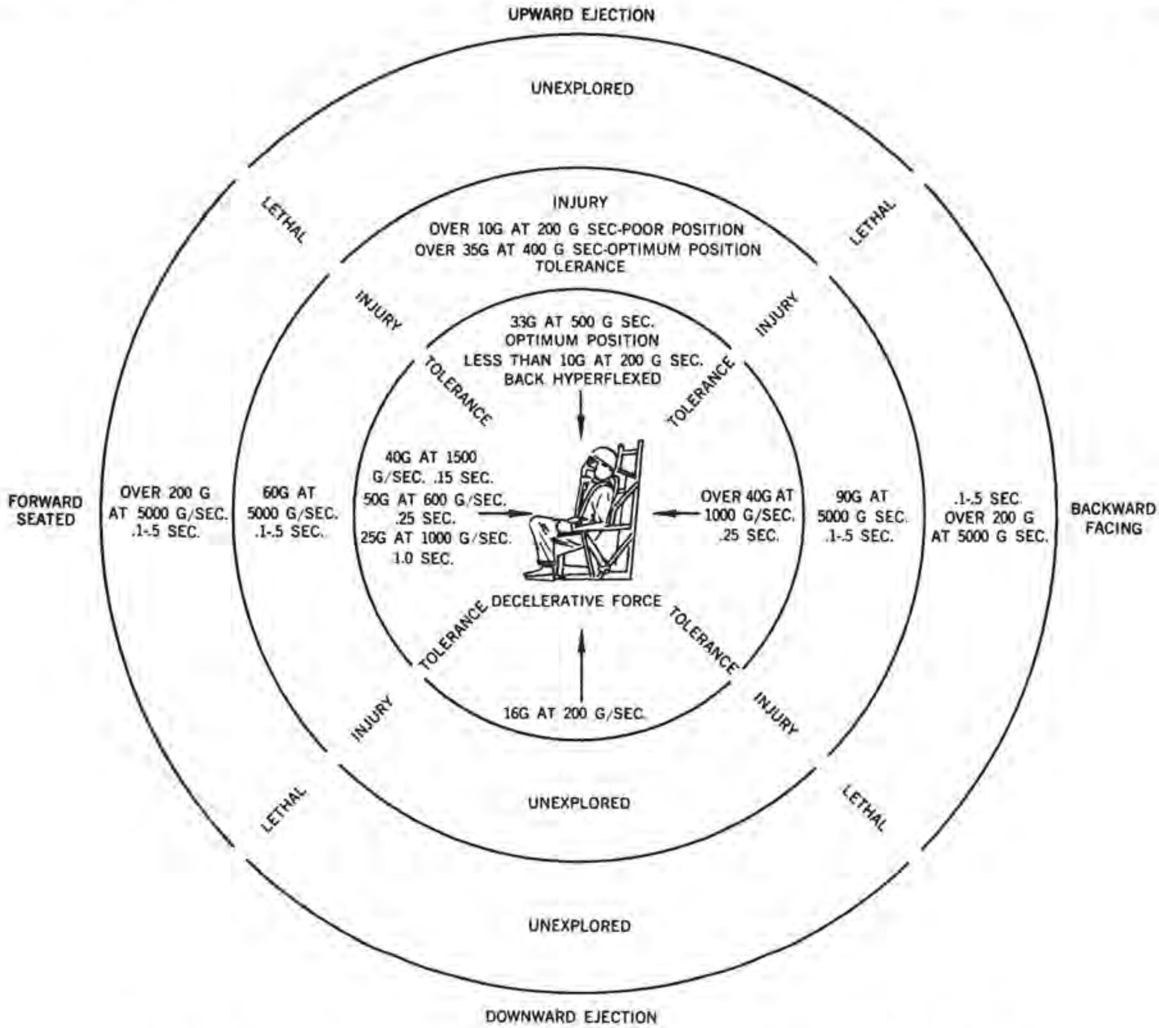


Figure 4–19. Tolerance, Injury and Lethal Limits for Force Applied Through the Principal Axes of Body Orientation.

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

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

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

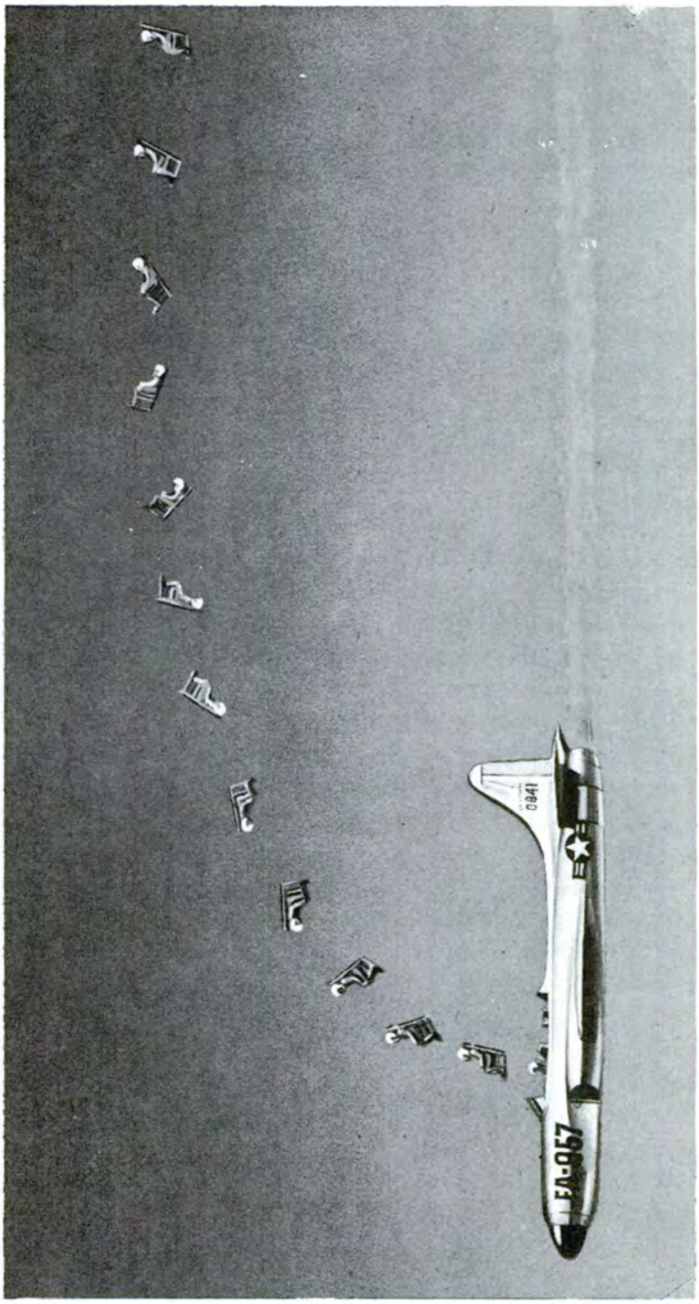


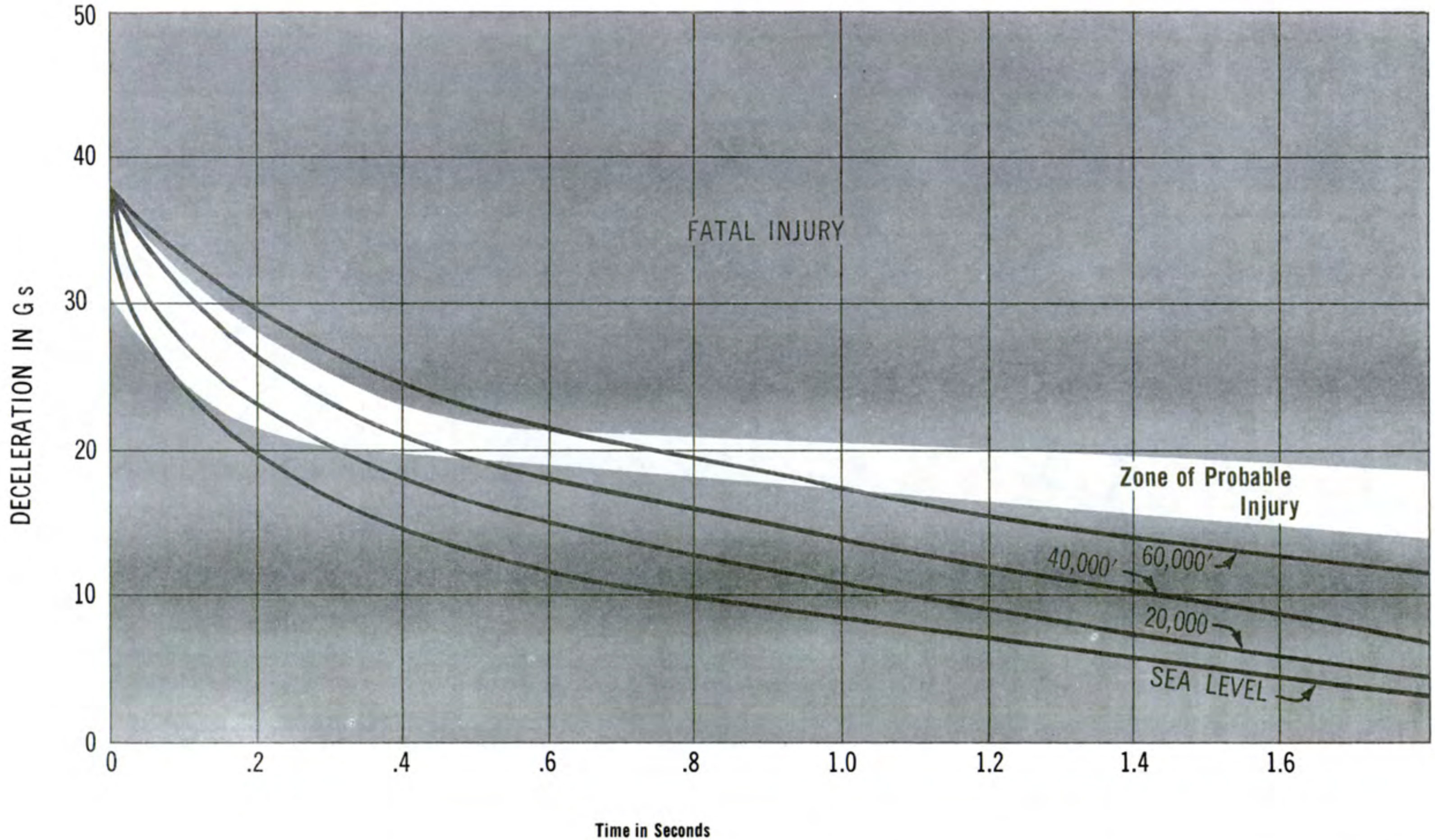
Figure 4–20. Tumbling Effect of an Ejection Seat.

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

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

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

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



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

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

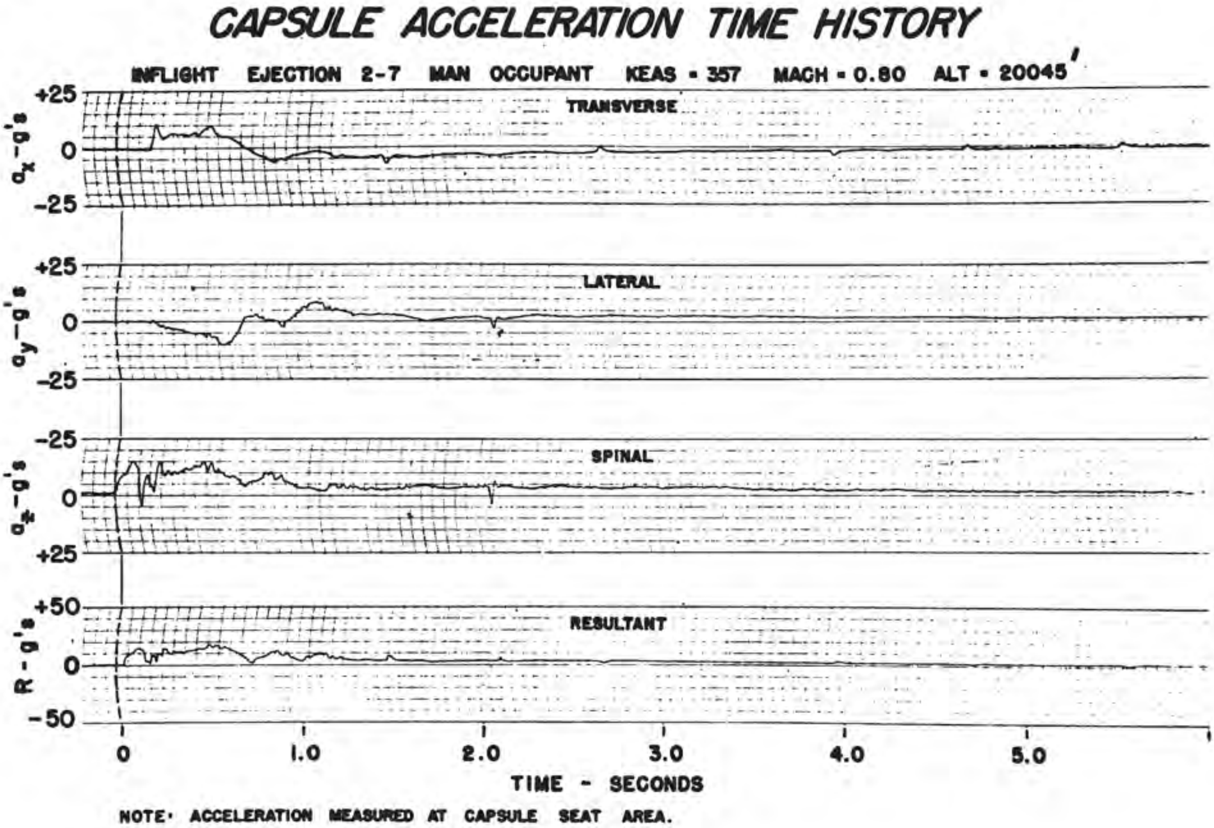


Figure 4-22.

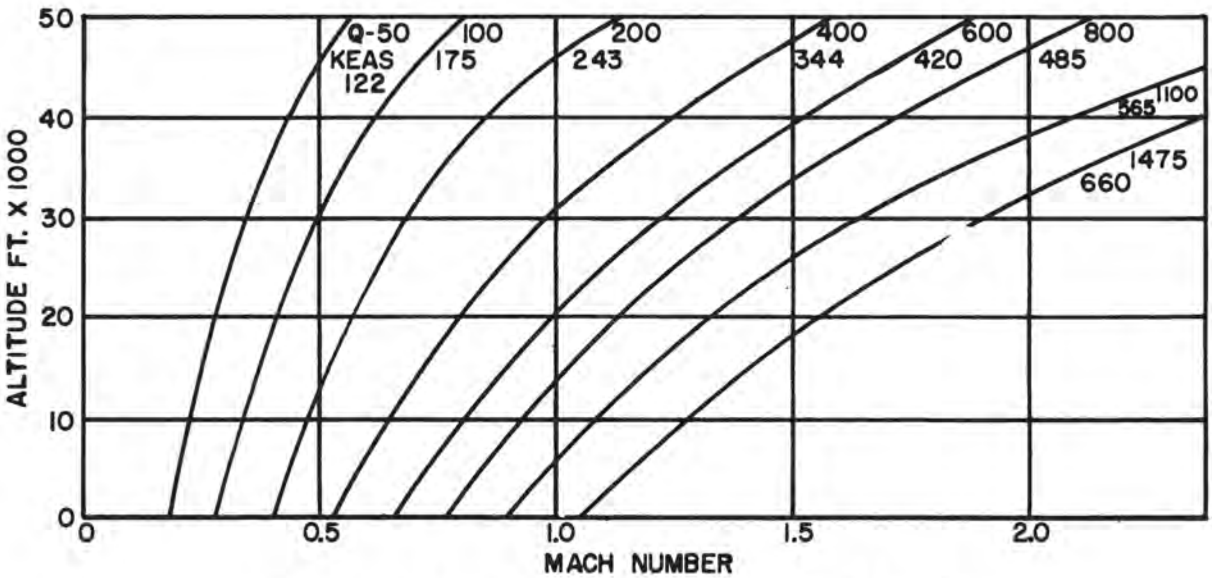


Figure 4-23. Q Force Related to Mach Number and Altitude.

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

Free-Fall

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

Parachute Opening Shock

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

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

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

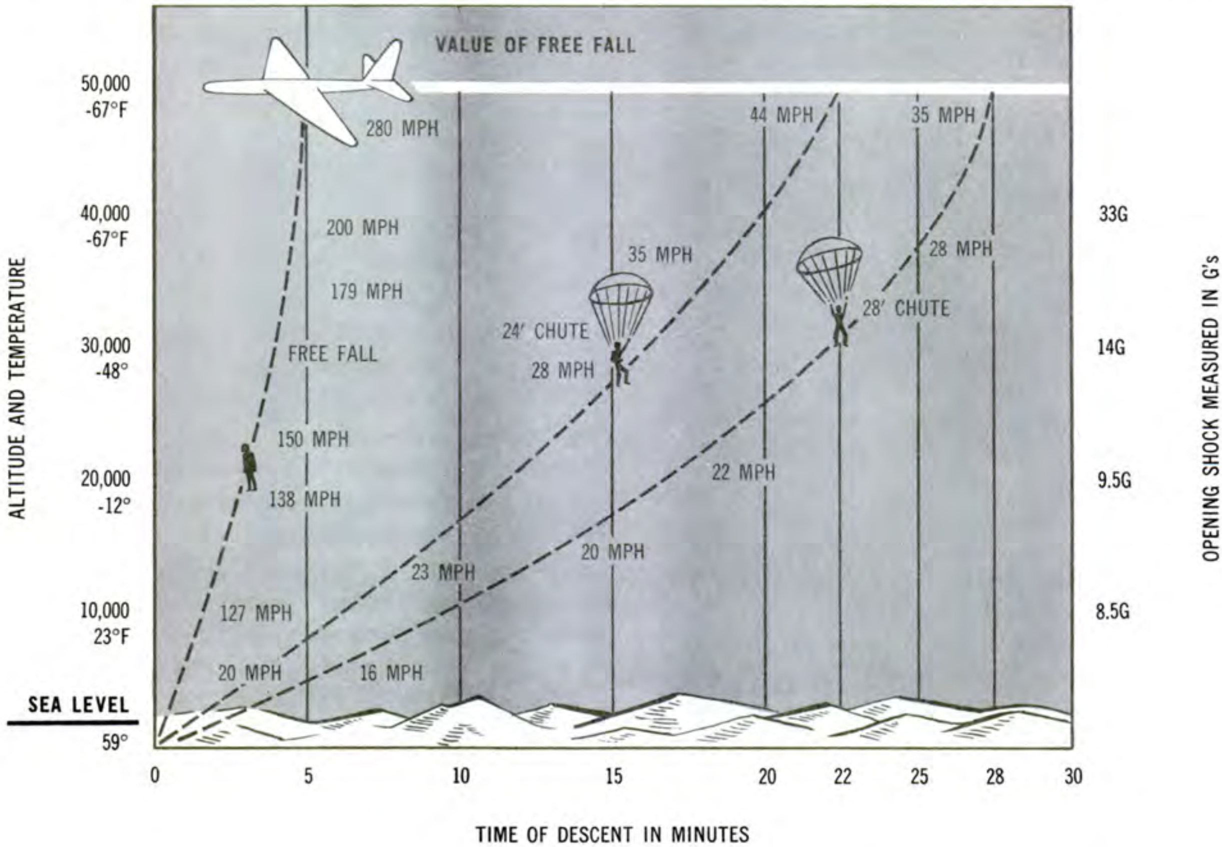


Figure 4–24. Calculated Rates of Descent for Free Fall and Open Parachute From 50,000 Feet and Lower for a Man Weighing 200 Pounds.

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

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

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

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

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

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

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

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

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

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

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

Landing

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

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

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

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

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

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

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

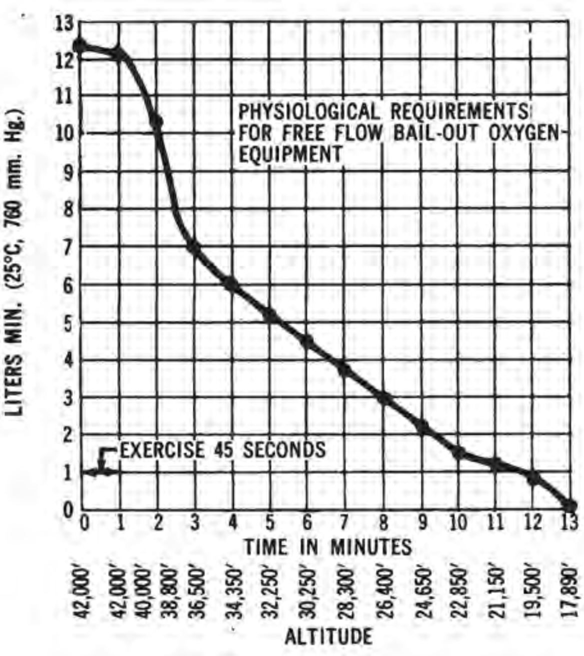
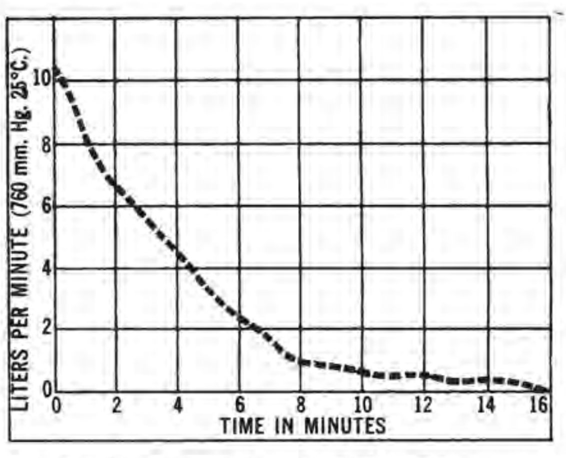


Figure 4–25.



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

Figure 4–26.

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

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

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

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

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

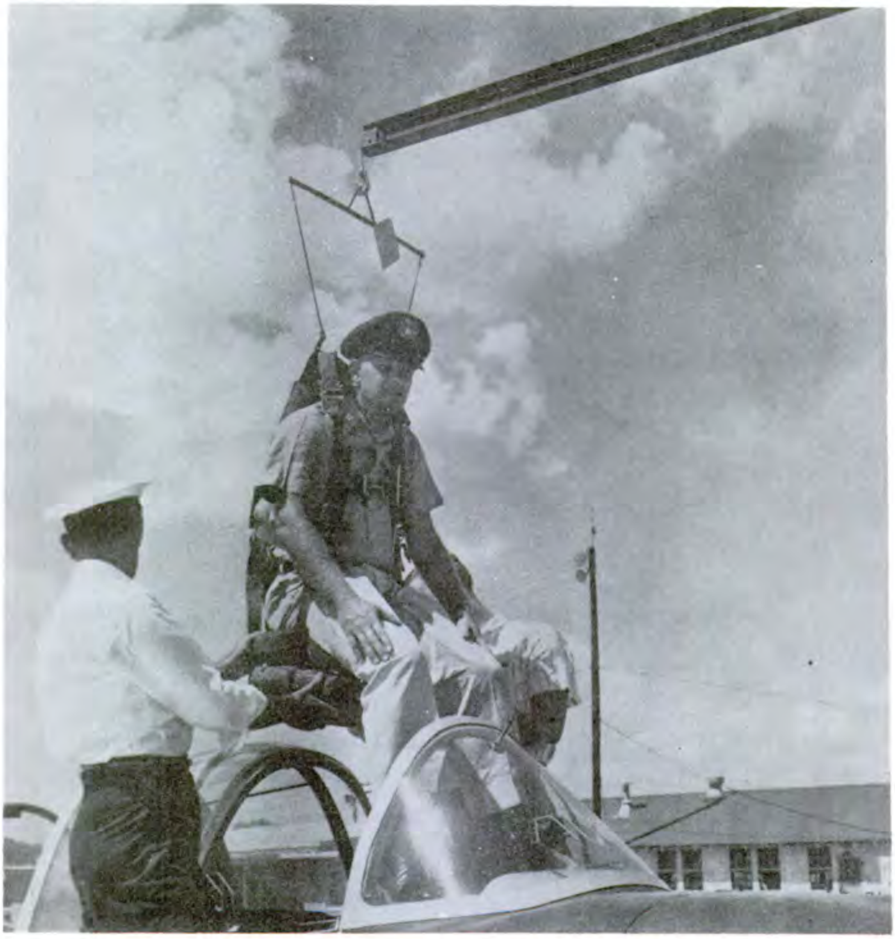


Figure 4–28. Demonstration of Sling Harness Used in Lifting a Back-Injured Pilot From the Cockpit. The Parachute Is Used To Stabilize and Support the Back.

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

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

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

Figure 4–29. The P–4B Helmet.

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

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

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

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Aerospace Medicine,* Chapter 16, Effects of Radial and Angular Accelerations, and Chapter 17, Effects of Linear Accelerations, The Williams and Wilkins Company, Baltimore (1961).

Fraser, T. M., *Human Response to Sustained Acceleration,* National Aeronautics and Space Administration (NASA) SP–103 (1966).

Frost, R. H., *Escape from High Speed Aircraft,* Aeronautical Engineering Review 14:35 (1955).

Figure 4–30. The HGU–2/P Helmet.

Goldman, D. E. and von Gierke, H. E., *The Effects of Shock and Vibration on Man,* Lecture and Review Series No. 60–3, Naval Medical Research Institute (NMRI) (January 1960).

Goodrich, J. W., *Escape from High Performance Aircraft,* USAF Aero Medical Laboratory, Wright Air Development Center Technical Note 56–7 (1956).

Hyde, A. S. and Raab, H. W., *A Summary of Human Tolerance to Prolonged Acceleration,* Aerospace Medical Research Laboratories (AMRL)–TR–65–36 (1965).

Lederer, L. G. and Putnam, L. E., *Comparison of Drowsiness Induced by Bonamine and Marezine,* Journal of Aviation Medicine. 29:885 (1958).

Miller, H., Riley, M. B., Bondurant, S., and Hiatt, E. P., *The Duration of Tolerance to Positive Acceleration,* Journal of Aviation Medicine. 30:360 (1959).

Neely, S. E. and Shannon, R. H., *Vertebral Fractures in Survivors of Military Aircraft Accidents,* Journal of Aviation Medicine. 29:750 (1958).

Nuttall, J. B., *The Problem of Spatial Disorientation,* Journal of American Medical Association. 166:431 (1958).

Parachute Opening, A Symposium on Escape From High Performance Aircraft, The Institute of Transportation and Traffic Engineering, University of California. (1959).

Phillips, P. B., and Neville, G. M., *"Emotional G" in Airsickness,* Journal of Aviation Medicine. 29:590 (1958).

Physiological Training, 2d Ed., USAF School

Figure 4-31. The HGU-6/P High Altitude Flying Helmet.

of Aviation Medicine, Air University (1958).

Pletcher, K. E., *USAF Emergency Escape Experience 1950-1959,* USAF Medical Service Digest 12:13 (1961).

Phoebus, C. P., Moderator: *Problems of Escape From High Performance Aircraft:* a Symposium; Journal of Aviation Medicine. 28:57 (1957).

AFP 161-16, *Physiology of Flight.*

Chapter 5

EFFECTS OF TEMPERATURE

Adequate protection of aircrews against the effects of temperature related to climate, the characteristics of the earth's atmosphere, and air friction of supersonic flight require a working knowledge of the meteorological, engineering, and aeromedical background of the problem.

The following are important considerations:

a. Temperature ranges of climate, atmosphere, and supersonic air friction.

b. Physiological accommodation to temperature variation within the range of tolerance.

c. Pathological reactions to temperature extremes.

d. Protection against the effects of temperature extremes.

e. Treatment of injuries resulting from temperature extremes.

AFP 160-4-1 provides Medical Service officers the information essential to the development of a preventive program to control the adverse effects of high temperature, and a guide to diagnosis and treatment.

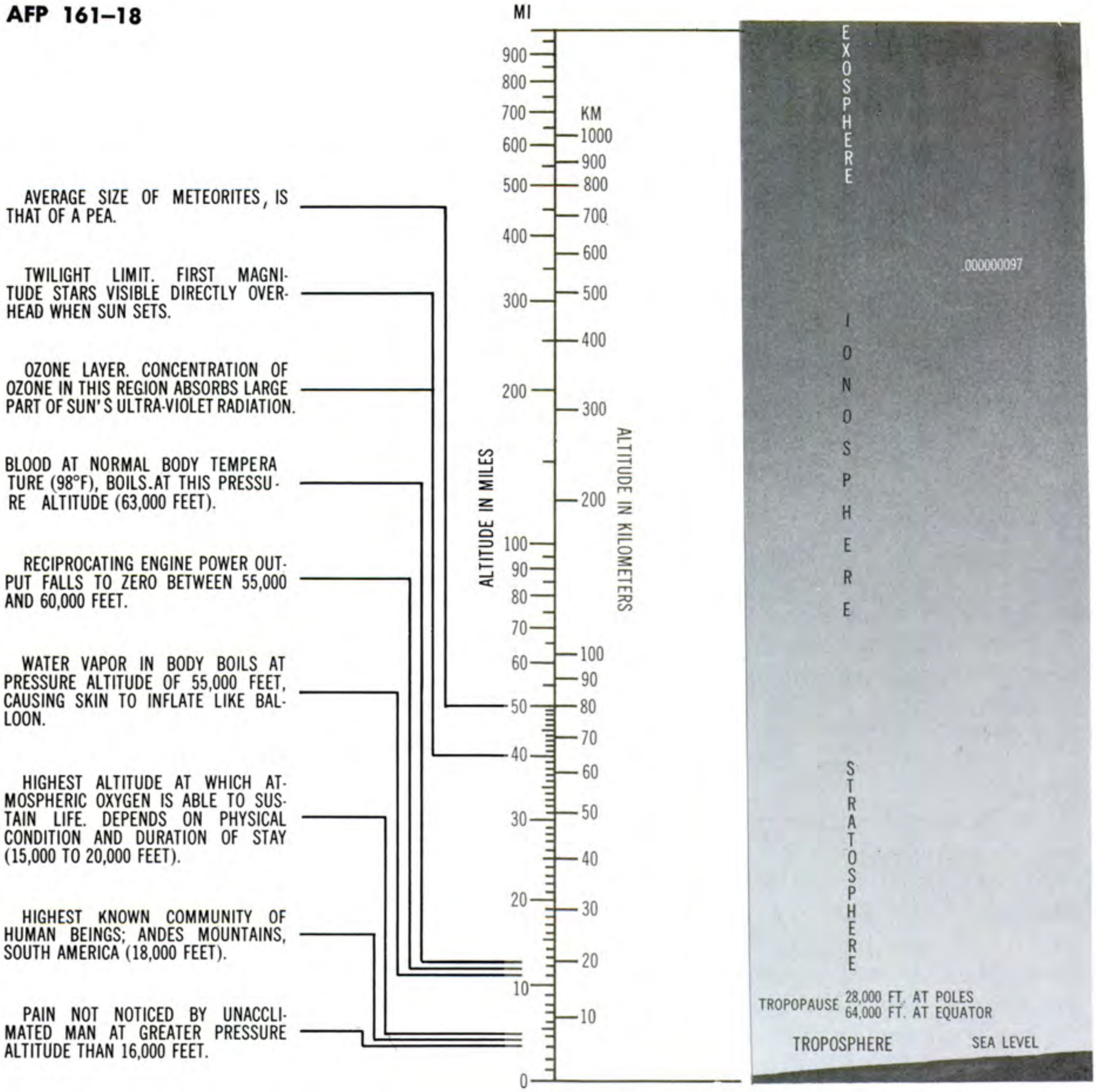
CLIMATE AND THE EARTH'S ATMOSPHERE

The extremes of geographic and seasonal temperatures encountered at the earth's surface range from −90° F to +140° F. This comprises a horizontal distribution of temperatures, subject to comparatively limited and gradual changes, with geographically distributed annual cycles. The extremes of this distribution are separated by the distance from the equator to the poles.

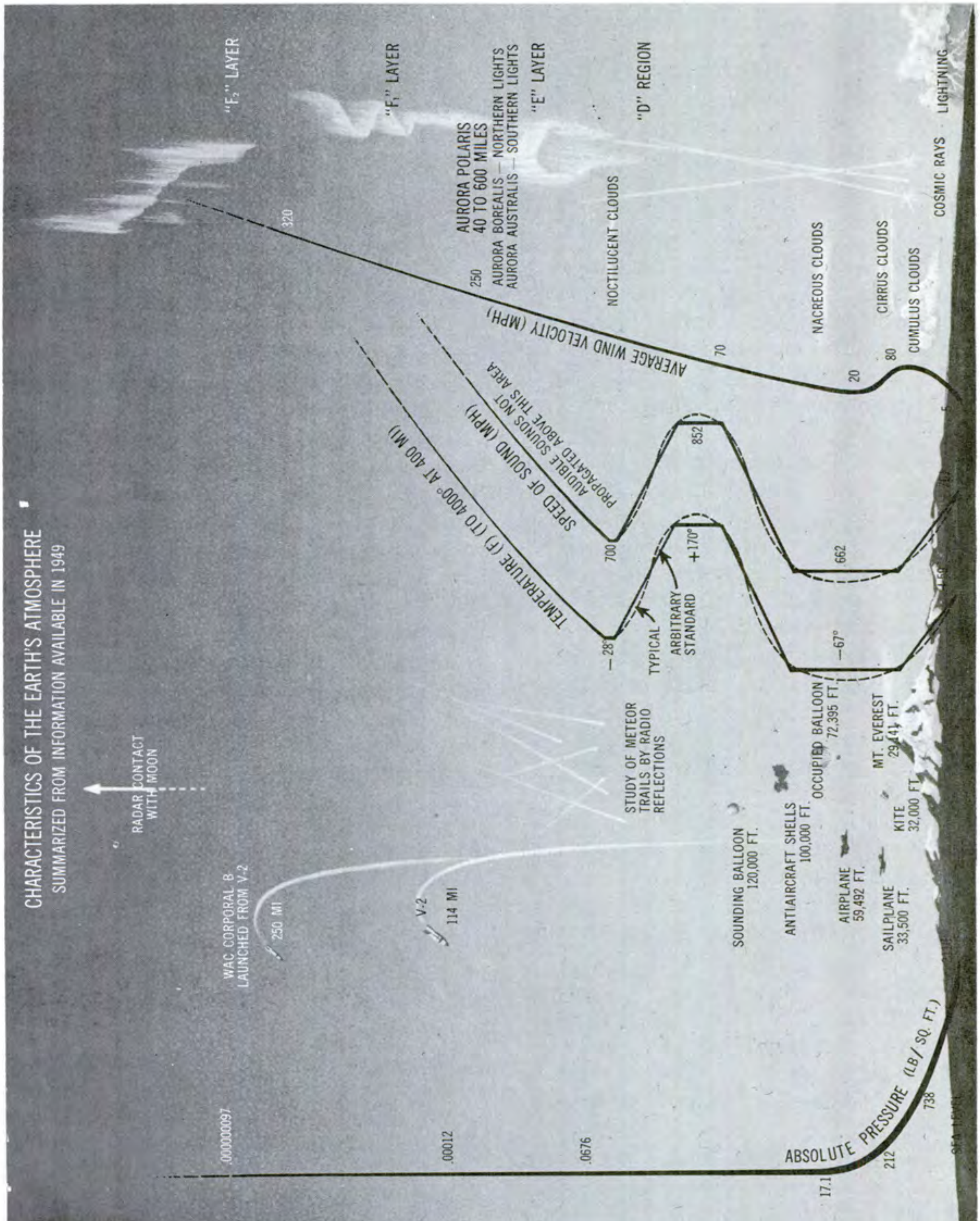
In contrast, the earth's atmosphere has a vertical distribution of temperatures in which the extremes are encountered within 50 miles above the earth's surface, and which are comparatively stable except in its lowest layer. The earth's atmosphere is divided into concentric shells. These are defined and described in the following paragraphs, beginning with the innermost shell.

The region of the atmosphere from 0 to 10 km (6.2 mi), where the temperature falls rapidly with increase of altitude, has long been called the *troposphere,* and the region from about 10 to 20 km (33,000 to 66,000 ft), where the temperature is approximately constant, is called the *stratosphere*. The *ionosphere* has its own well-accepted nomenclature, the terms D, E, F_1, and F_2 designating the four ionized regions with maxima of ionization at about 70, 100, 200, and 300 km (43.5, 62.1, 124.3, 186.4 mi), respectively. Aside from these, there is no generally accepted terminology of upper atmospheric regions.

The terms "upper" and "outer" atmosphere are used with different meanings depending on the context, and it is best to keep their meanings fairly elastic. The region from about 20 to 35 km (12.4 to 21.7 mi) which embraces most of the ozone has been called the *ozone layer* or *ozonosphere*. It has been proposed that the region from the top of the stratosphere, at about 20 km (12.4 mi), to the minimum of temperature, at about 70 km (43.5 mi), be called the *mesosphere*—and the region of increasing temperature, somewhere about 100 km (62.1 mi), the *thermosphere*. The *exosphere* has been used to refer to the outer fringe of the atmosphere, where the air particles execute long elliptical orbits bouncing outward from impacts with other particles and falling back under gravity. In general, the physical properties of the various regions are not yet well enough known to permit their fixation by an accepted terminology.


AVERAGE SIZE OF METEORITES, IS THAT OF A PEA.
TWILIGHT LIMIT. FIRST MAGNITUDE STARS VISIBLE DIRECTLY OVERHEAD WHEN SUN SETS.
OZONE LAYER. CONCENTRATION OF OZONE IN THIS REGION ABSORBS LARGE PART OF SUN'S ULTRA-VIOLET RADIATION.
BLOOD AT NORMAL BODY TEMPERATURE (98°F), BOILS AT THIS PRESSURE ALTITUDE (63,000 FEET).
RECIPROCATING ENGINE POWER OUTPUT FALLS TO ZERO BETWEEN 55,000 AND 60,000 FEET.
WATER VAPOR IN BODY BOILS AT PRESSURE ALTITUDE OF 55,000 FEET, CAUSING SKIN TO INFLATE LIKE BALLOON.
HIGHEST ALTITUDE AT WHICH ATMOSPHERIC OXYGEN IS ABLE TO SUSTAIN LIFE. DEPENDS ON PHYSICAL CONDITION AND DURATION OF STAY (15,000 TO 20,000 FEET).
HIGHEST KNOWN COMMUNITY OF HUMAN BEINGS; ANDES MOUNTAINS, SOUTH AMERICA (18,000 FEET).
PAIN NOT NOTICED BY UNACCLIMATED MAN AT GREATER PRESSURE ALTITUDE THAN 16,000 FEET.
MI
ALTITUDE IN MILES
KM
ALTITUDE IN KILOMETERS
EXOSPHERE
.000000097
IONOSPHERE
STRATOSPHERE
TROPOPAUSE 28,000 FT. AT POLES
64,000 FT. AT EQUATOR
TROPOSPHERE
SEA LEVEL


Wind Pattern
SUB-POLAR
TROPICAL CALMS
DOLDRUMS
TROPICAL CALMS
CORE



EARTH'S STRUCTURE

The earth's interior, like its exterior environment, is presently defined as consisting of several concentric layers of material. The earth's crust is believed to have solidified between 2 and 3 billion years ago. The crust, which is called the continental layer, is approximately 30 miles thick, and is the only solid layer. The second layer is called the mantle, and extends to a distance of about 1200 miles below the earth's crust. The central core is estimated to be about 5500 miles in diameter. The temperatures and pressures which exist within the earth are many times those which exist in the atmosphere. It has been estimated that the temperature and pressure at the center of the earth's core are 3500 to 5500 degrees Fahrenheit and 3½ million times the pressure at the earth's surface, respectively. These extreme pressures cause the density of the earth's core to be increased to four or five times the average density of the crust.

The boundary between the troposphere and the stratosphere is called the *tropopause*. It is closest to the earth at the poles (approximately 6 miles) and farthest away at the equator (approximately 10 miles).

The troposphere is characterized by a constant rate of decrease in air temperature as the height above the earth increases, by turbulent air, and by the varying amounts of moisture content. All weather phenomena occur in the troposphere, for they are inherently associated with the physical properties of temperature gradient and moisture content.

Winds have been observed up to nearly 30 km (18.6 mi) altitude with sounding balloons. Average monthly data at sunset near Omaha, Nebraska, showed that the wind velocity increased with altitude from about 10 statute miles per hour at the surface to about 60 mph at 12 km (39,000 ft) where the stratosphere began. As the altitude increased to 20 km (65,000 ft), the wind velocity decreased to 20 mph and then increased to 35 mph at 28 km (92,000 ft). By means of smoke shells exploded at 30 km (18.6 mi) it was found that the average summer and winter velocities were 27 and 83 mph respectively. A maximum value of 147 mph was recorded in the winter.

The temperature ranges encountered in the various layers of the upper atmosphere are shown in the accompanying chart.

Radiant energy from the sun is absorbed at the earth's surface, except for that which is absorbed by clouds. The heating and cooling of the earth's surface is dependent on the duration and intensity of exposure to solar radiation.

All temperature phenomena in the atmosphere are caused by the presence of water vapor and by its absorption of long-wave radiation from the earth. Near the earth's surface, a body of air absorbs, by radiation from the earth, more heat than it can lose by reradiation to other bodies of air and the heavens. When the temperature of a body of air increases, the air rises. As it ascends, it expands because of decreasing atmospheric pressure. With expansion, the rising body of air cools, precipitating part of its moisture in the form of clouds. Hence, its absorption of heat by radiation from the earth decreases.

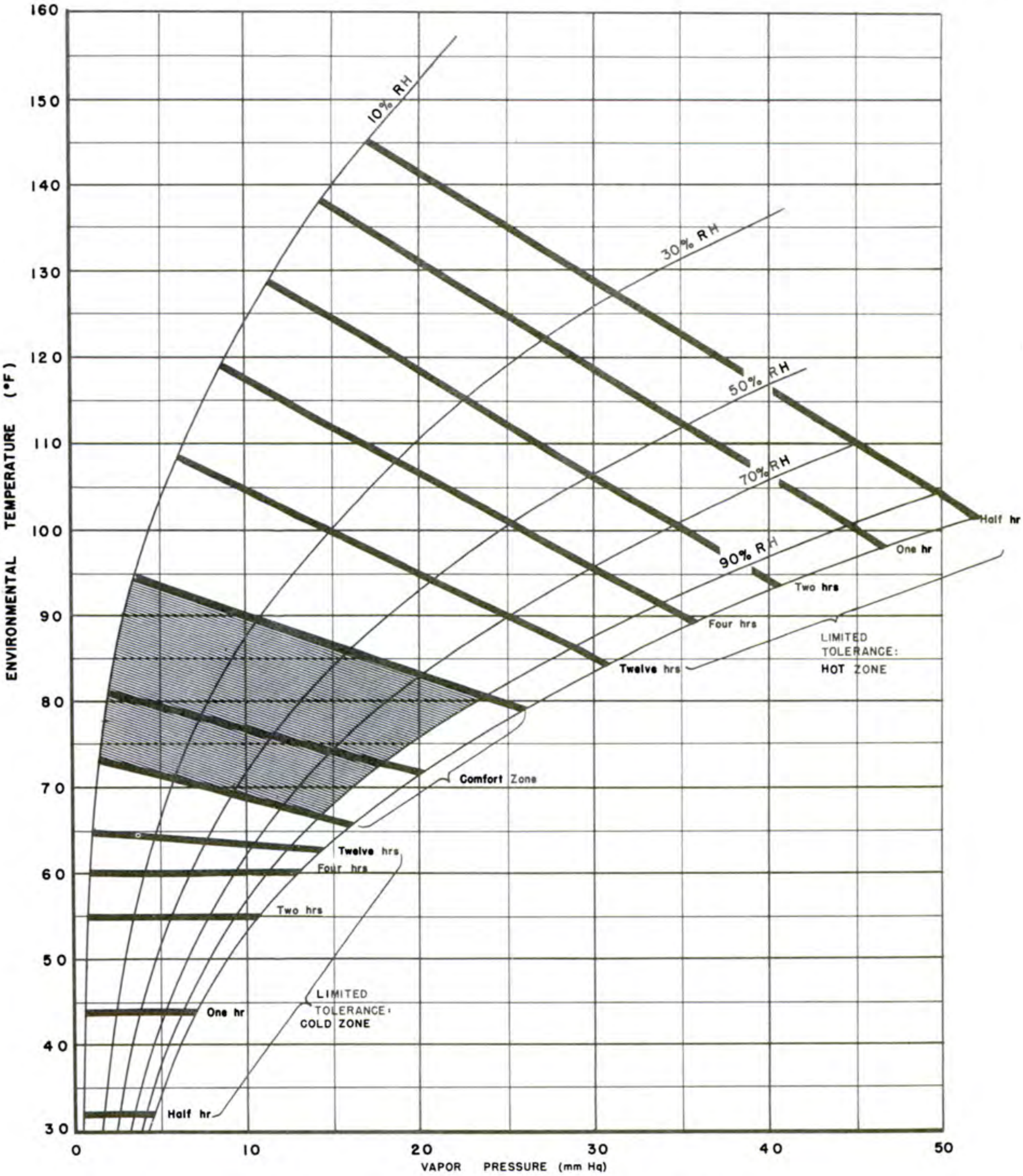
By repeated cycles of these physical phenomena, which are commonly known as "weather," relatively constant stratospheric temperatures of approximately −55° C are maintained. The water content of air in the stratosphere is so low that a balance exists between the absorption of radiation from the earth and reradiation to the heavens, resulting in a region of comparatively constant temperature.

Stratospheric temperature varies with latitude, being lowest over the equator at −80° C (−112° F), and highest over the poles at −40° C (−60° F). Temperature reversals may occur above the equator in the upper levels of the stratosphere. Reversal temperatures of +170° F are encounterd in the transition from stratosphere to ionosphere.

Inversions of temperature have been observed near the earth's surface. *For example*, at the polar regions this inversion is very pronounced. At Ladd AFB, Alaska, ground temperatures of −40° C or −45° C are not uncommon in the winter, while at the same time, at 8,000 feet, temperatures as high as −5° C may exist. Extreme cold (that is, less than −40° C) is usually encountered either on the ground or in the stratosphere, but practically never at 10,000 feet, regardless of latitude.

AIRCRAFT CLIMATES

Modern military aircraft have very efficient cabin and cockpit air-conditioning systems. Adequate ventilation, heating, and cooling are maintained as required by the aircrew members. Adjustment of automatic controls is usually the only requirement for the maintenance of a satisfactory climatic environment. This is true with such aircraft as the F-86, F-89, F-94, Century-Series Fighters, and the B-47, B-52, B-58, and other jet aircraft. Problems do arise, however, as a result of mechanical failure of accessory equipment—usually the air expansion turbines used for cabin refrigeration. Under



Sitting man dressed in conventional clothing (I clo) doing light manual work.
Air motion equals 200 fpm.

(See MR No. TSEAL-3-695-56)

Figure 5–1. Thermal Requirements for Tolerance and Comfort in Aircraft Cabins.

these circumstances, very high cockpit temperatures may be produced which are quite intolerable for long periods of time. The thermal requirements for human tolerance and comfort in aircraft cabins for temperature range +30° F to 160° F are presented in figure 5-1.

Extreme heat due to solar radiation is encountered in aircraft standing on the ground and in fighter craft at low and moderate altitudes (up to 10,000 feet). In parked aircraft, internal air temperatures may reach 15° to 20° C higher than outside temperature because the hot metal of the fuselage heats the impounded cabin air. Plexiglas canopies create a "greenhouse" effect in planes parked or flying under solar radiation. This effect is due to inward transmission of visible and near-infrared radiation, thus heating the occupant and the walls of the cabin, which in turn reradiate far-infrared waves. However, since plexiglas has a low transmission for long infrared, radiant energy is "trapped" with a resulting increase in temperature.

The advent of high-performance aircraft, flying at speeds in and beyond the sonic range, has raised a further potential hazard in respect to heat loads on the cockpit enclosure. Heating of the cabin by compression of the atmosphere surrounding the aircraft and by skin friction can reach 800° F at 1,150 miles per hour near sea level. Protection from this heat is afforded by refrigeration cooling devices. The rapid rise of air and wall temperatures which would result in the event of failure of the refrigerated air-conditioning has been simulated in laboratory experiments. The results of these are summarized in figure 5-2. It shows the length of time healthy young men can tolerate the various levels of heat, the tolerance limit being the attainment of a physiological state close to fainting. In addition, preliminary results of experiments investigating the ability to perform flying tasks are shown, indicating the earliest point in heat exposure at which such performance was observed to start deteriorating, in a study of four experienced pilots at three temperatures.

REGULATION OF BODY TEMPERATURE

In common with other mammals, man possesses a delicate homeothermic mechanism that responds to the physical processes of heat transfer to maintain body temperature of 37° C.

Physical Processes

Conduction. This is the transfer of heat through a solid, liquid, or gas from one molecule to another at a rate depending upon the specific thermal conductivity of the material and the temperature gradient between the two points under consideration. The heat exchange between man and his environment by conduction is ordinarily small.

Convection. Natural or gravity convection is the process by which a liquid or gas, coming into contact with a source of heat, is heated, expands, and rises as it is displaced by the heavier, cooler liquid or gas that surrounds it. Prevailing winds or mechanical ventilation produce "forced" convection. Convection losses from the body are increased by low temperature, wind, and movement of the body.

Radiation. This is the transfer of heat by radiant energy through space in the direction of diminishing temperature gradient between two bodies. The human body receives heat by radiation from objects in the environment that are hotter than the body, notably the sun, and loses heat by radiation to the environment when the latter is cooler than the body. Radiation transfers are proportional to the size of the temperature gradient and body area exposed.

The sum of radiated and convected transfers, either from the body to the environment or vice versa, is related to the total temperature gradient (Newton's law of cooling). For a practical grasp of most cooling and heat-load problems, it is convenient to consider them together.

Evaporation. The body is enabled to lose heat by the process of vaporization of water from the surface and from the respiratory mucosa. Such transfer of heat derives from the fact that, in the transformation of water into vapor, heat is taken up from surrounding materials. At usual skin temperatures, the value of 0.58 kilocalories per gram of water vaporized is commonly accepted.

Stored Heat. Because of its large capacity, the body is further able to withstand cooling and heating stresses with a minimum shift in temperature. About 66 kilocalories of heat is transferred when the body cools or heats 1° C. Critical hypothermia or hyperthermia results when change in storage reaches approximately 180 kilocalories in the average man, but at lesser transfers, storage may be considered as an adaptive mechanism.

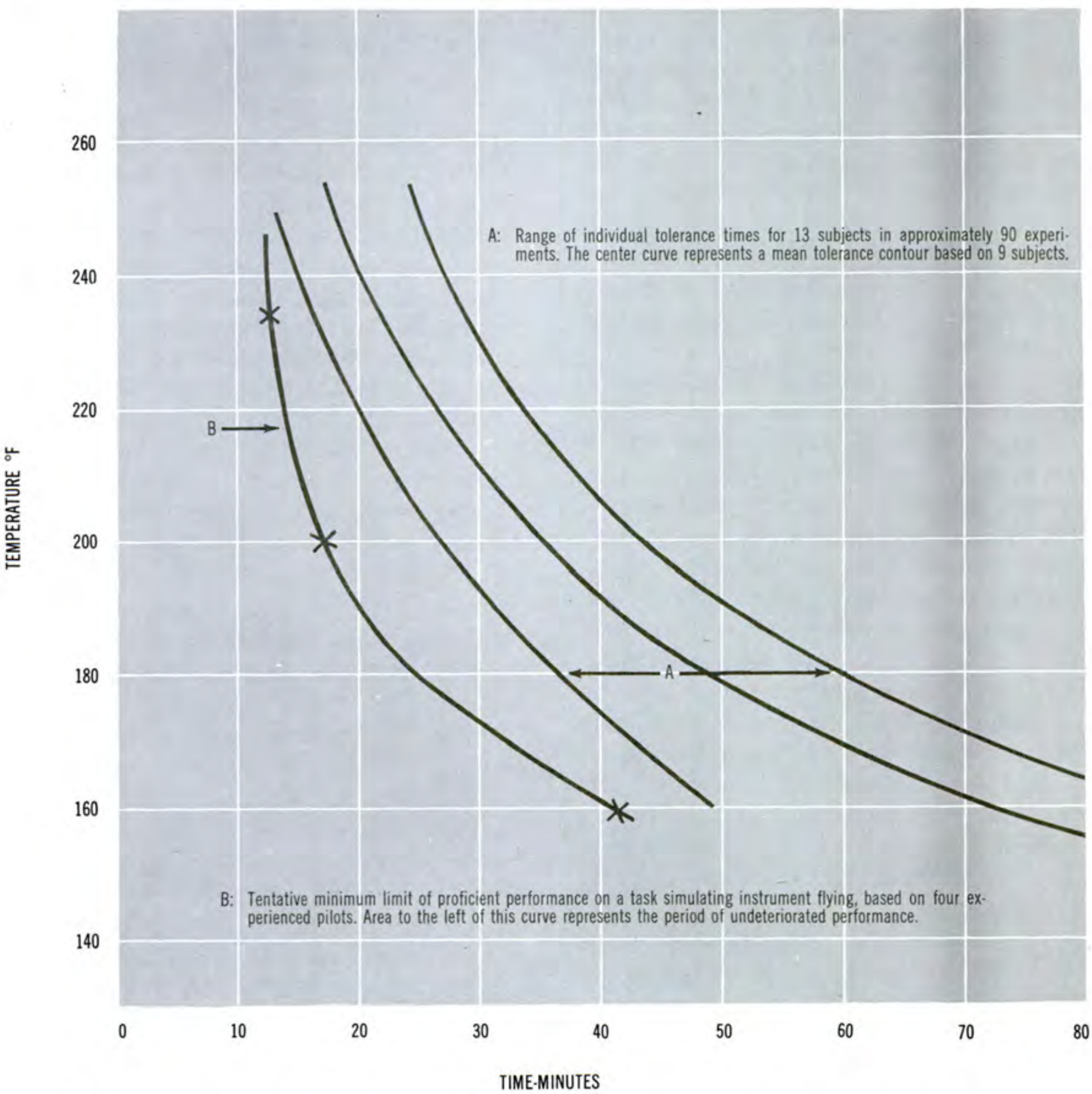


Figure 5-2. Limits of Tolerance and Performance Proficiency at Extreme Temperatures.

Ordinate values represent average air temperature, assuming wall temperatures approximately equal to that of the air and a constant humidity of 0.8 inches mercury vapor pressure (20mm Hg). This humidity level is equivalent to a relative humidity of 80% at 79° F or 41.5% at 100° F.

If the absolute humidity were lower than the above value, all contours would move to the right, and vice versa.

Physiological Processes

Vascular. Alteration in peripheral circulation constitutes one of the most important phases of regulation. Effective flushing of skin is accomplished not only by changes in tone of arterioles, venules, and capillaries, but also by the state of arteriolar-venular anastomoses (Sucquet-Hoyer canals), which are most numerous in the extremities. The primary importance of the sympathetic nervous system in this type of vasomotor activity is well established. Afferent impulses that alter vasomotor tone may arise from many sources, including reflexes from the skin (particularly of the extremities) and from brain centers. Vasodilatation, on the other hand, is caused by a local thermal stimulus, although the possibility of a specific vasodilator reflex mechanism is strongly suggested.

Metabolic. Under normal environmental conditions, the basal metabolism is 40 to 50 kilocalories per square meter of body surface per hour, and the processes of physical regulation are adapted to dissipate this amount of heat. At low temperatures, increased muscle tone (thermal tone), involuntary muscular activity (shivering), and voluntary muscular exertion all act to raise the heat production and thus, to restore body temperature. In addition, epinephrine, by virtue of its calorigenic effect, may be a significant factor in regulating body temperature. A small increase in metabolism during hyperthermia has been consistently found in man and experimental animals; it is attributed to acceleration of many of the chemical processes of metabolism.

Respiratory. Similar to metabolism, the respiration is augmented at temperatures both above and below the neutral temperature zone. At low temperature, ventilation increases, in part, as a result of heightened metabolism and reflex effects of the cold. At high temperatures, a deepening of the respiration, often associated with a sensation of air hunger, is a sign that the limit of tolerance is being approached. Usually the rate of breathing is not altered.

Secretory. Although insensible water losses occur at all temperatures, thermal sweating begins at a skin temperature of 33° C and increases in proportion to heat load. Sweat losses may amount to 2 to 3 liters per hour in strong subjects working in the heat. Temperature of the blood is considered to be the most important stimulus, but sweating may begin before a rise in body temperature occurs.

Zones of Thermal Regulation

Zone of Body Cooling (24° C and Lower). As the environmental temperature is reduced below the neutral range, and the cooling of wind is added, stored heat is lost, as shown by skin and rectal temperatures. Cutaneous vasoconstrictor activity is no longer adequate and, with cooling of the blood and skin surfaces, muscular hypertonus and shivering occur. At still lower temperatures, these trends reach their extremes, resulting in a pale and constricted skin ("goose flesh") and heavy shivering, which may elevate metabolism to three times the basal rate. Though final breakdown of thermal control depends upon the degree of physical activity, amount of clothing, and duration of exposure, three eventualities may occur:

a. If activity is restricted, the extremities, notably toes and fingers, approach freezing temperatures most rapidly, followed by depression of general body temperature. This type occurs most frequently in aircrew members.

b. If the individual is physically active, cooling develops with fatigue, and as exhaustion approaches, the vasoconstrictor mechanism is overpowered, sudden vasodilatation occurs with resultant rapid loss of heat, and critical cooling ensues. This is most frequent in arctic or cold-weather expeditions.

c. A third type is represented by "immersion foot" or "trench foot." Here, pathological effects are caused by continued exposure to cold without freezing. The prolonged vasoconstriction interferes with the nutrition of the skin and results in accumulation of catabolites. Subsequent warming results in extreme reactive hyperemia with edema.

Zone of Vasomotor Regulation (25° to 29°

C). In this temperature range, characterized by sensations of thermal comfort, the processes of heat production and loss are so poised that variations in cutaneous vasoconstrictor tone are adequate to maintain thermal balance. Essentially, the skin serves as a variable insulator. With cutaneous vasoconstriction, skin temperature is lowered and heat losses caused by convection and radiation diminish, but vasodilatation elevates skin temperature and increases these losses. Changes in stored heat and metabolism are small in this zone.

Zone of Evaporative Regulation (29° C and Higher). The primary defense against hyperthermia is provided by evaporation of water from the surfaces of the skin and from the mucosa of the respiratory tract. Secretion of sweat is the active physiological process, accounting for most of the water available for evaporation. When environmental temperatures are higher than skin temperatures, and especially on exposure to intense solar radiation, the evaporation may be inadequate to balance the gain by radiation and convection; hyperthermia, characterized by a rising body temperature and accelerated pulse, supervenes. A slight increase of metabolism is caused by the thermal stimulus—the greatest effect is flushed skin resulting from maximal vasodilatation. The consequences of failure of heat adaptation may take different forms depending on type and duration of exposure and on the state of acclimatization of the individual:

a. "Heat exhaustion" or "heat prostration" results from an inadequacy of the circulatory system to meet the demands for heat regulation imposed by high environmental temperature and humidity. Contributory causes in healthy individuals include disturbances of fluid balance such as result from salt depletion.

b. "Heat cramps" in the skeletal muscles are caused by excessive loss of sodium chloride in the sweat. This condition occurs typically in persons who undergo heavy exertion in the heat.

c. "Heat stroke" (sometimes called "sunstroke" when observed in open areas where solar radiation is excessive) occurs when the heat-dissipating mechanism fails, allowing the internal body temperature to rise to danger levels.

Physiological Climate Stresses

Except in very special circumstances, which are seldom of practical importance, environmental temperature is properly represented by the air temperature. This obviously varies with season, climate, and weather, but its standard relationship to altitude is of most interest to the Flight Surgeon.

Cooling Stress—Low Temperature. In general, cooling stress is proportional to the total gradient between the skin and the environmental temperature. This determines the rate of heat loss from the body by radiation and convection.

Wind exerts a cooling effect upon an object warmer than its environment, as in the case of the human body exposed to cold. The magnitude of this cooling is represented in figure 5–3 which gives curves of relationship between the percentage increase in the calorie demand (the total gradient between the skin and air temperatures) and wind velocity for various amounts of clothing (expressed in *clo*). On bare skin, the cooling effect of wind acts in this instance to blow away the insulation afforded by layers of warm air at the skin surface, increasing markedly with velocity. With very heavy clothing (4 clo) the maximum cooling effect of wind is relatively small. Cooling stress is, therefore, proportional to the cooling gradient, and the added effect of wind is obtained by use of the appropriate curve in the figure, when wind velocity and the amount of clothing worn are known.

Heat Load—High Temperature. The heat load (heating stress) of the atmosphere is also proportional to the temperature gradient between the body surface and the environment, but the relationship here is the opposite of that which causes cooling, the body gaining heat by radiation and convection. There are two important additional factors: the effect of humidity on evaporative loss and the added heat gain from solar radiation.

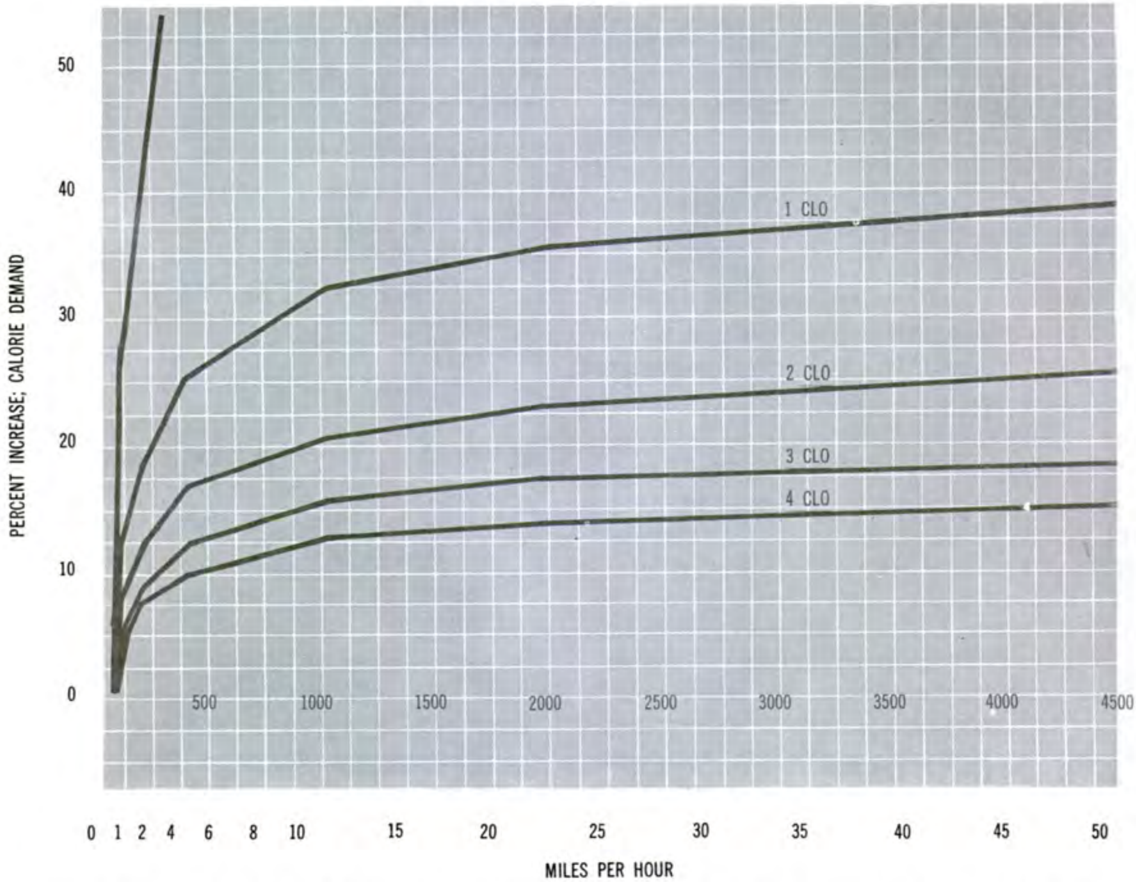


Figure 5–3. The Cooling Power of Air According to Velocity and Amount of Clothing Worn.

The temperature-humidity effect can best be assessed in terms of physiological tolerance. See figure 5–4 for tolerance limits for clothed, sitting subjects. It is noted that, in general, a much higher temperature can be tolerated when the humidity is low (desert conditions) and that the tolerable temperature is lowered as high humidity is approached (jungle conditions). Line AA gives comfort limits. Lines BB and CC show limits at two levels of physiological adjustment: BB gives the boundaries of evaporative cooling without hyperthermia, while CC assumes more stringent conditions in which approximately 50% of the total adaptive capacity of the acclimatized individual is utilized in a 2-hour exposure. With shorter exposures, of course, more extreme temperature-humidity conditions may be tolerated, as shown by lines DD and EE.

Outdoor exposures in hot climates usually involve additional heat load from incident solar radiation, which has been calculated to be 240 kilocalories per hour or two to three times the resting metabolism. Such a heat load can be tolerated when the humidity is low; however, it is of practical interest to note that high humidities, solar radiations, and air temperatures do not occur simultaneously in any known climate on the earth. Generally speaking, all hot climates are tolerable for the suitably acclimatized man, except for occasional very temporary occurrences of intolerable extremes of these conditions.

The Acclimatization Processes

Acclimatization to Cold. Changes in thermal sensation are an outstanding accompaniment of long-term exposure to cold. In the temperature zones, all persons experience

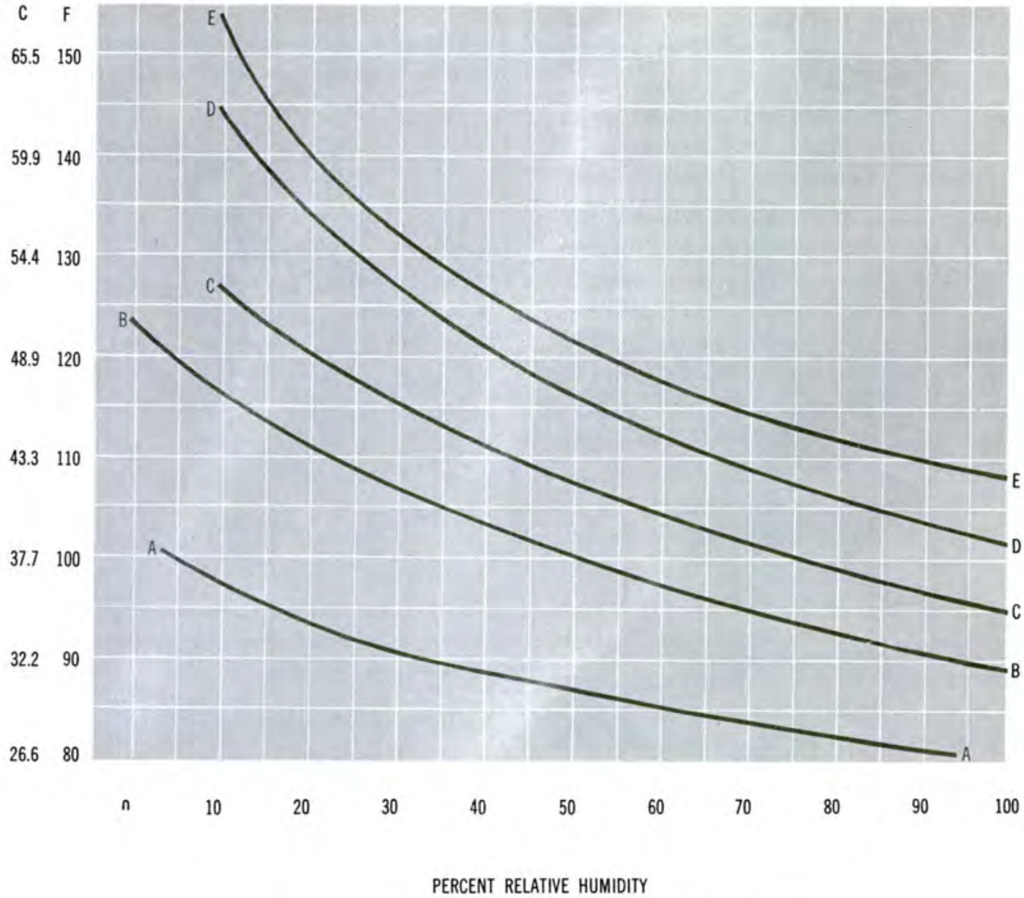


Figure 5-4. Relationship of Temperature—Humidity Effect.

The limiting environments of temperature and humidity for human tolerance, employing criteria which range from easy to difficult: AA, the upper limits of summer comfort zone; BB, the limits of evaporative cooling, with little or no rise in body temperature; CC, the limits of compensated hyperthemia; DD, 60-minute tolerance limit; and EE, 30-minute tolerance limit. (Winslow, Herrington and Gagge; Robinson, Turrell and Gerking.)

this type of adaptation to some degree during the winter season. Authorities disagree on the extent and duration of changes in metabolism with human acclimatization, but the metabolism of rats is increased by long exposure to cold if the adrenals are intact. Other studies emphasize the role of the thyroid gland in maintaining a higher metabolism under these conditions. Higher protein diets prevail in cold climates, and the specific dynamic action of this food element elevates metabolism. Whatever the nature of the psychological and physiological changes entailed and the extent of individual variation, acclimatization to cold is a matter of common observation.

Acclimatization to Heat. The major changes occur within a week and are chiefly cardiovascular in nature. During this period, the circulation adapts itself to the greatly increased cutaneous blood flow necessitated by the demands of heat dissipation. Heat stroke is prone to occur if exposure and activity are extreme, but its incidence is reduced as adaptation is achieved. Internal and skin temperatures, which increase abnormally in the heat, assume more normal values with acclimatization. The pulse rate also becomes stable with acclimatization.

Later adaptations include increased loss of sweat, more dilute sweat and, according to some authorities, increased plasma volume. Apathy, lack of desire to exert oneself, anorexia, and many other symptoms of maladaptation, which occur on initial exposure, become moderate or disappear entirely with acclimatization. In general, there are no qualitative differences between acclimatization to hot-dry and hot-humid conditions, and cross-acclimatization is effective. Gradations in exposure and activity in the heat are recommended to ease the transition from the unacclimatized to the acclimatized state.

PROTECTIVE CLOTHING

Thermal Insulation. The insulation of the body against cold may be measured in *clo* units. The *clo* is defined as that amount of insulation which will maintain normal skin temperatures when heat production is 50 kilocalories per sq.m. per hour, air temperature is 70° F, and air movement is 20 ft. per min. It corresponds roughly to the clothing worn by men in a temperate zone during the warm part of the year. It has the insulating value of a cloth approximately 0.42 cm thick.

The relationship between clothing (in *clo* units) required for various environmental temperatures is shown in figure 5-5. Two facts stand out:

a. The thermal insulation of the clothing determines the temperature that can be withstood in comparative comfort for a 6-hour period or longer, but for shorter exposures protection is afforded to much lower temperatures.

b. The limit of insulation with clothing is placed at 4 *clo* because such clothing is about 1-inch thick, which is the practical limit of permissible bulk and weight.

Windproofness. If wind penetrates the surface of clothing or enters openings at the neck, waist, sleeve, or trouser cuff, as much as 30% of the insulation intrinsic in the garment may be lost through forced convection of the entrapped air. Windproofness of the surface clothing depends upon tough, close-woven shell materials of long staple cotton. Adequate closures should be provided.

Thermally Adequate Footgear and Handgear. High surface-to-volume ratios and thermosensitive variations of blood flow to the extremities predispose them to rapid and extreme cooling. Practical coverings may seldom exceed 2 *clo* because of physical limitations. This maximum of protection is reached in footgear by the use of adequately large shoes or boots and several pairs of woolen socks. Suitable gloves must afford a compromise between the opposing requirements for insulation and dexterity. The practical solution lies in selecting the thickest glove that will permit necessary manipulative tasks to be performed and in supplementing this with warming mittens, donned when fine dexterity is not required.

Clothing Assemblies

The following lists various clothing assemblies and their temperature ranges:

(1) Extra heavy temp. range:
−22° F to −65° F

(2) Heavy temp. range:
+14° F to −22° F
Both covered by:
(a) Heavy aircrew assembly
(b) Heavy flying assembly

(3) Intermediate temp. range:
+14° F to +50° F
Intermediate flying suit

(4) Light temp. range:
+50° F to +86° F
(a) Light zone flying jacket
(b) Light flying suit

(5) Very light temp. range:
+86° F to +122° F
Very light flying suit
cotton (Byrd cloth)

(6) Ventilated antiexposure suit temperature ranges:
Bailout at −70° F
Cold Water Immersion
Arctic Exposure
Cabin Air/Wall Temperature
+165° F

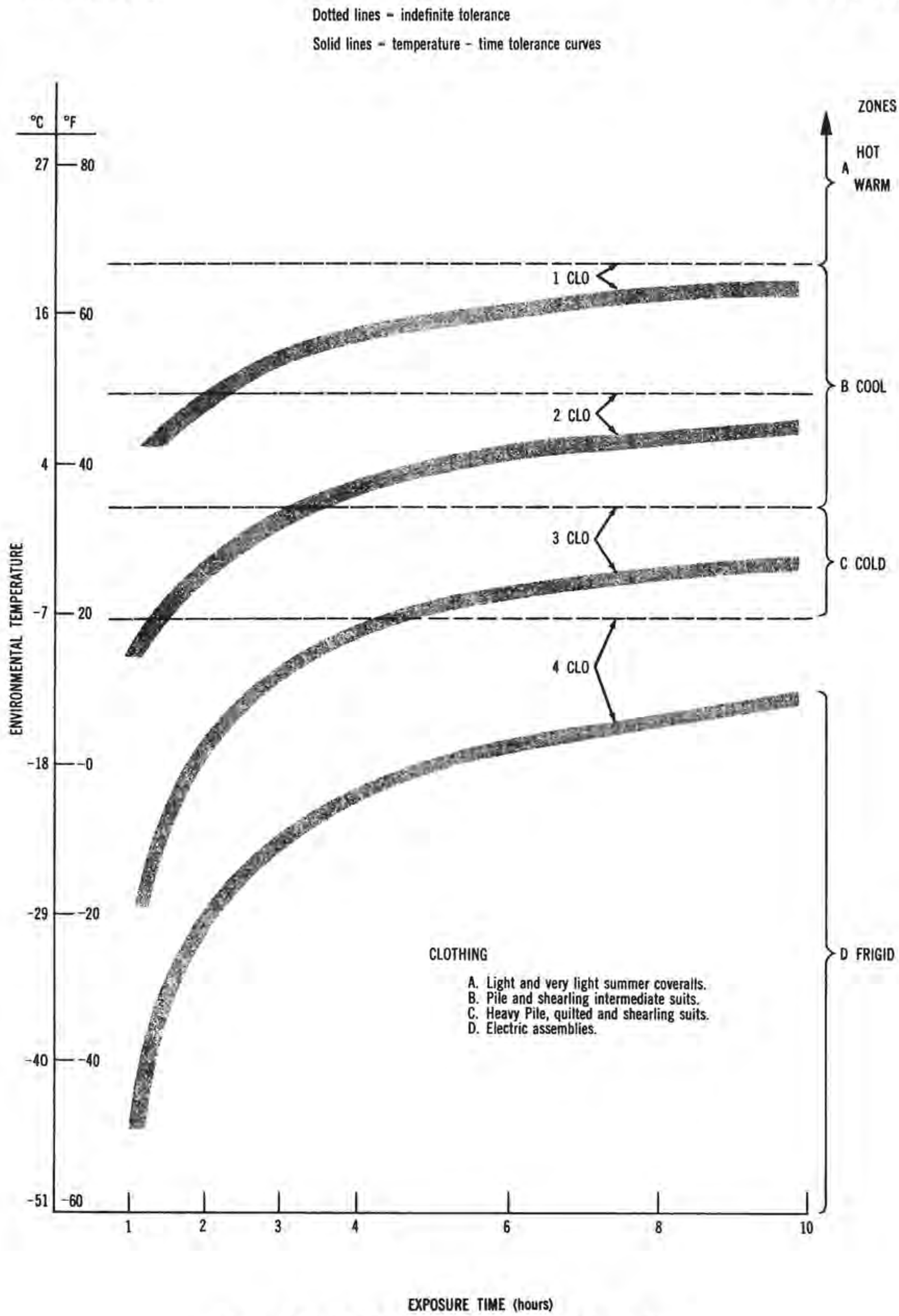


Figure 5–5. Cold Tolerance Curves With Clothing.

This clothing assembly consists of the following items listed in the sequence of donning:

1. Heavy woolen underwear.

2. Anti-G-suit or K2B coverall.

3. One pair of medium weight wool socks.

4. The type MA-2 ventilating garment.

5. The type MD-3A coverall (insulation liner).

6. The type MD-1 antiexposure suit.

For the operation of this clothing assembly, an air source is necessary, capable of delivering up to 13.5 cfm of air against a back pressure of 7″ of water. The temperature range of this ventilating air must extend from 50° to 120° F depending on the thermal situation to be dealt with. The air source can either be the air-conditioning system of the aircraft or a specially developed, small, light-weight blower which is installed into the cockpit and utilizes cockpit air for ventilation.

Warm and Hot Zone Clothing. From 30° C up to the temperature-humidity limits of human tolerance, very lightweight clothing is used. Provided the clothing is permeable to vapor, its effect upon heat tolerance is small. In hot-humid conditions little or no effect of lightweight clothing is found, but in the hot-dry range, and with the additional load of solar radiation, clothing serves to increase heat tolerance, particularly in extremely hot environments where the tolerance duration is short. Here, insulation reduces the inward transfer of heat by radiation and convection, while evaporation loss is little impaired. This furnishes an explanation of the custom among desert peoples of wearing lightweight but flowing garments which keep the head and body well covered.

COLD-WATER IMMERSION

Protection of aircrews against emergency exposure to cold-water immersion has required the development of special survival or antiexposure suits. These suits have been developed chiefly along two lines: (a) Those designed to prevent entrance of water—*i.e.*, the "dry" suit principle; and (b) use of the "wet" suit principle in which no attempt is made to prevent water entry, but protection is provided by sealed insulation (unicellular foam rubber, *for example*) and by restricting circulation of the entering water.

Thermal protection with both types of antiexposure suits and consequent potential rescue time are much extended when the cold-immersed crewmember enters his life raft. Based on presently available experimental and operational data, figures 5-6 through 5-8 are predictive graphs showing human tolerance to cold-water exposure. Figure 5-6 illustrates the predicted tolerance time for the crewmember wearing wet clothing and remaining in the cold water. For convenience, short-time intervals are indicated. In figure 5-7, tolerance time in cold water with both the wet and dry suit is plotted. Figure 5-8 indicates tolerance time for the crewmember within the raft and exposed to various ambient air temperatures. These predictive data are based on the use of a canopy-type (MB-IV) raft. Predicted tolerance times are also based on average physiologic cold response rather than on that of the exceptional or cold-resistant type. Heat production of 75 calories per square meter per hour and a body surface area of 1.8 square meters are also assumed. If rescue is accomplished within the predicted tolerance time, serious injury or fatality should not occur. However, it should be emphasized that individual physiologic variation is extreme in this type of exposure, and this fact should always be kept in mind in rescue operations. The data are based on the assumption that adequate thermal protection of the hands and feet is provided. This, unfortunately, is technically difficult to provide under the more extreme exposure conditions (*i.e.*, air temperatures below 32° F and water temperatures below 40° F).

Local Cold Injury (Including Frostbite)

Exposure of limited body areas to local cold may produce abnormalities which vary from minor functional disturbances to actual gangrene. These various degrees of injury

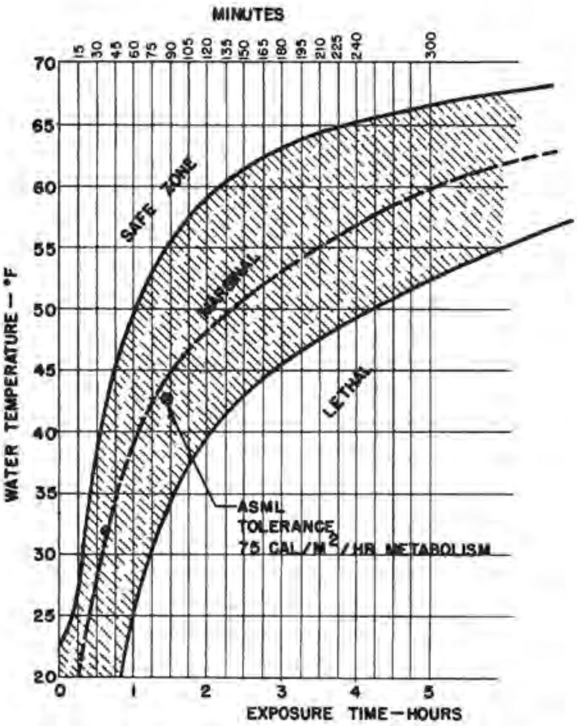


Figure 5–6. Tolerance Time in Cold Water With Wet Clothing.

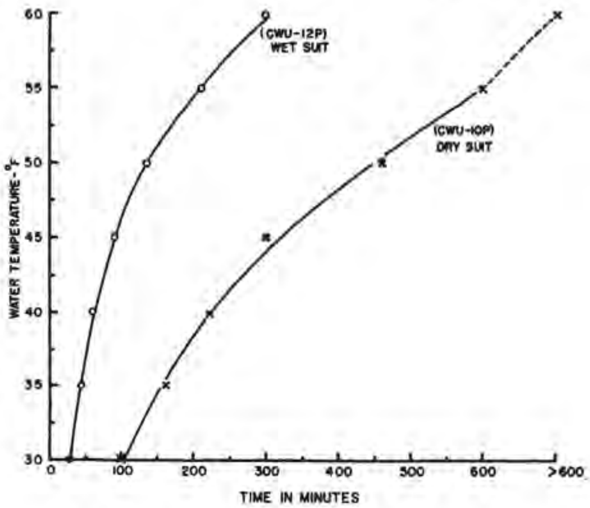


Figure 5–7. Tolerance in Cold-Water Immersion.

may result whether or not the tissues freeze. This emphasizes that the attained tissue temperature is not all-important, but rather the product of temperature and exposure time. This observation classifies the cold stimulus with other physical and chemical agents, the effects of which are represented by the intensity-time curve so well known in physiology and toxicology.

From a pathologic point of view, frostbite, trench foot, immersion foot, and shelter foot are the same. These specific terms merely describe the physical conditions under which the injuries are incurred. The term "local cold injury" should be used to include all such injuries. Even clinically it has been recognized that the symptoms and signs do not differ qualitatively in the so-called various types of local cold injury. Quantitatively, the signs and symptoms will depend on the severity of damage and the amount of tissue involved.

Incidence in the Air Force. From August 1942 to January 1944, 2,008 crew members of the Eighth Air Force were frostbitten on combat missions. During the same time 1,362 men received wounds from enemy gunfire. Ten and one-half days on the average were lost from flying duty by each thermal casualty, and 7% of the men affected were lost permanently. The average loss from frostbite for the entire period was 0.58% of all men dispatched on heavy-bomber missions.

After July 1943, improvement in design, supply, and care of the electrically heated flying equipment resulted in a decline in the frequency with which hands and feet were affected by the cold. During the same period, frostbite of the face, neck, and ears rose proportionately.

From January 1944, the rate of frostbite per thousand man missions steadily declined from 0.50% to reach a low of 0.03% by August. Many factors were contributory, but most important were: reduction in wind blast, particularly in the waist gunner's position in the B-24 and B-17; careful indoctrination of flying personnel by the flight surgeons; and particular care, supervision, and improvements in electrically heated equipment by the personal equipment officers.

Etiology. As stated above, the degree of local cold damage depends primarily on the actual temperature in the tissues and the duration of the exposure. Secondary factors

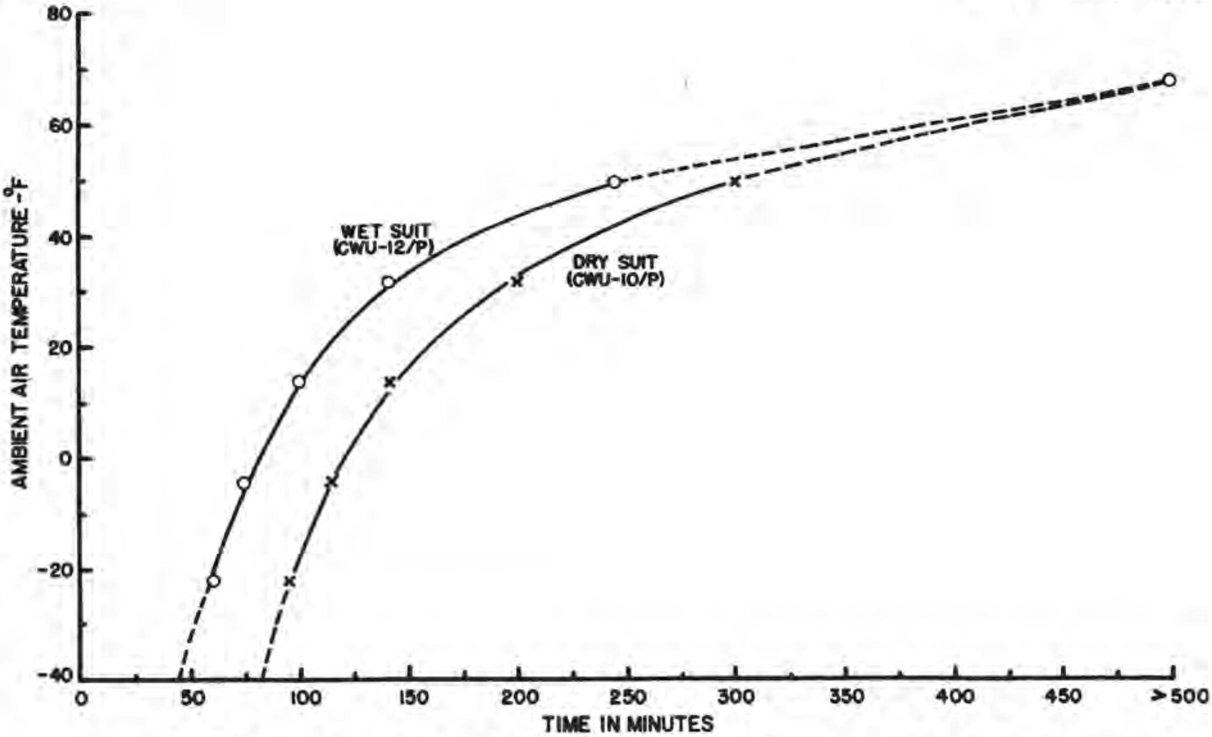


Figure 5–8. Tolerance in Raft Exposures (Following Water Immersion, at 32°F, Not Exceeding 5-Minutes Duration).

which play a part in the development of local cold injury are: wind velocity; contact with substances which alter heat conductivity (metal, moisture, etc.); changes in body temperature; degree of physical activity; and impairment of the circulation by body attitudes, clothing, or equipment.

Physiology and Pathology. When tissues are exposed to severe frostbite *in vivo*, vasoconstriction occurs followed by blanching and solidification. As long as the tissues are maintained in the frozen state, no other demonstrable changes occur, since at these temperatures no measurable metabolism occurs. With thawing, however, another series of events results: a. Hyperemia; b. edema (may produce skin blisters) with or without hemorrhage; c. necrosis; and d. healing.

The vasoconstriction during exposure to cold has a dual origin: direct action of the cold on the vessels and reflex nerve action. Lewis and Love theorized that the remarkable vascular events seen after thawing are set in motion by the action of a histamine-like substance from the tissue cells injured by freezing. Such a substance has not been demonstrated. The vasodilatation accompanying thawing may be due to paresis or paralysis of the cold-injured vessel walls.

Opinion is divided concerning the actual cause of tissue necrosis from cold. One group believes that the damage is due to direct action of cold on tissue cells. Another assumes that tissue damage is secondary to the vascular changes either stasis with sludging of the red cells in capillaries or actual thrombosis. Evidence presented up to the present indicates that cold injury is a true thermal injury just like a burn, but we cannot exclude with certainty the possibility that the abnormal vascular reactions caused by cold do contribute to the injury.

Not all tissues show the same degree of susceptibility to cold injury. This can be demonstrated experimentally by choosing a degree of cold injury that will cause gangrene of the muscles of an animal's extremity without resulting in necrosis of the overlying skin.

The sequence of increasing cold injury,

beginning with the mildest changes and progressing to complete gangrene, occurs in the following order:

(1) Loss of skin sensitivity, muscular paralysis, and atrophy.

(2) Muscle necrosis without skin necrosis.

(3) Combined muscle and skin necrosis.

(4) Complete loss of all exposed tissue from gangrene.

When necrosis is incomplete, connective tissue proliferates and replaces the gangrenous areas to a variable degree.

Gangrene of frostbitten tissue is of the dry type, provided secondary infection does not occur.

Symptoms and Signs. The symptoms are often mild and transient. This fact is unfortunate in that the afflicted individuals are not sufficiently warned of the impending danger. Often, relatively mild stinging or prickling is the only symptom noticed. The involved parts then tend to become anesthetic and turn white, waxy, and ultimately solid. During thawing of frozen parts, local pain is generally marked. Hyperemia and edema (often with skin blisters) become evident and tend to disappear in 3 to 4 days.

The skin becomes dull blue-gray in color, often with areas of hemorrhage. Depending on the degree of injury, the skin recovers or becomes gangrenous. In the former case, the skin appears thinner, shinier, and of finer texture than normal—a picture of atrophy. When necrosis of skin occurs, a demarcation line develops in 5 to 6 days between the viable and nonviable tissue and dry gangrene finally results. Sensation in recoverd parts is impaired for a variable period of time.

Prophylaxis. The prevention of local cold injury in Air Force personnel consists of adequate and proper use of clothing, indoctrination regarding the dangers of exposure to cold, and the construction of military aircraft to reduce the exposure of occupants to wind and cold.

TREATMENT

It must be borne in mind that there can be produced in tissues a degree of cold injury that precludes recovery. Therefore, when an extremity is exposed to very severe frostbite it is possible that three indistinct zones representing different degrees of injury are present: a. That which is injured beyond recovery as far as any known therapy is concerned, b. that which is severely injured but which may, in part at least, be saved from gangrene by adequate treatment, and c. that which is minimally injured and will recover with or without therapy. Treatment should be directed toward saving as much of the second zone as possible.

Our ideas concerning the rate of rewarming of frostbitten tissues have changed in the past few years. Several investigators have shown experimentally in animals and one in humans that, contrary to popular belief, rapid thawing of tissues frozen from relatively short exposures results in less loss of tissue from gangrene than does slow thawing. Rapid warming in 42° C water until the tissues become soft is especially beneficial with respect to skin. The good results with muscle are also definite but not as striking. Furthermore, function of limbs exposed to cold injury is much better maintained after rapid thawing.

It is not known how long the rapid warming can be delayed and still be beneficial, nor is it known whether rapid warming will be beneficial when the cold injury is incurred from long exposure. Since it is possible to demonstrate tissue damage within minutes after exposure to cold, it is probable that the beneficial results from rapid thawing will be less as the time of exposure to cold becomes longer.

The question as to the advisability of artifically causing vasodilatation or vasoconstriction as therapeutic measures has not been decided. Those who believe that the tissue damage is due to ischemia incident to vasoconstriction or stasis advocate vasodilatation by drugs, sympathectomy, or injection of sympathetic ganglia. Others believe that edema, which occurs after thawing, results in tissue hypoxia and death and, therefore, recommend constriction of the vessels.

The use of heparin in the treatment of experimental frostbite has been advocated by Lange and collaborators. Unfortunately, other investigators have not been able to reproduce their results. The rationale of heparin therapy is based on the hypothesis that cold-induced tissue necrosis is due to vascular thrombosis. There is much experimental evidence against this idea, and from the experimental results using heparin it is very doubtful that it is of value. In fact, it is questionable that any form of specific therapy will be beneficial once the cold-injured tissues have been returned to body temperature.

Avoidance of trauma to frostbitten parts must be emphasized. Massage or exercise of the parts while frozen is to be avoided. Cold injuries should be treated as other types of wounds resulting from physical causes—frostbitten upper extremities should be immobilized in slings and individuals with frozen lower extremities should be transported on litters.

The prevention of secondary infection is of paramount importance. Cold-injured parts should be treated aseptically by careful cleansing and covering with sterile dressings. The topical application of powdered sulfa drugs is not indicated. However, the local use of ointment in which 5% sulfa powder is incorporated reduces infection and also prevents the dressings from adhering to the parts. Antibiotics should be used as indicated. Prophylactic inoculation against tetanus is indicated in the more severe local cold injuries.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Aerospace Medicine,* Chapter 19, "Temperature Stresses," Williams and Wilkins Co., Baltimore (1961).

Beckman, E. L., *Thermal Protection During Immersion in Cold Water,* Report No. 1 (MR 005.13-4001.06), Naval Medical Research Institute, Bethesda, Md., 27 March 1964.

Blockley, W. V., *et al., Human Tolerance for High Temperature Aircraft Environments,* Journal of Aviation Medicine, 25:515-522 (1954).

Carlson, L. D., *et al., Adaptive Changes During Exposure to Cold,* Journal of Applied Physiology, 5:672-676 (1953).

Glaser, E. M., *Immersion and Survival in Cold Water,* Nature, 166:1068 (1950).

Hall, J. F., Kearny, A. P., Polte, J. W., and Quillette, S., *Effect of Dry and Wet Clothing on Body Cooling at Low Air Temperatures,* Wright Air Development Center Technical Report 57-769, May 1958.

Hall, J. F., Polte, J. W., Kelley, R. L., and Edwards, J., Jr., *Skin and Extremity Cooling of Clothed Humans in Cold Water Immersion,* Journal of Applied Physiology, 7:188, September 1954.

Hunter, J. C., *Effects of Environmental Hyperthermia on Man and Other Mammals: A Review,* Military Medicine Volume 126, No. 4, 273-281, April 1961.

Minard, D., *Prevention of Heat Casualties in Marine Corps Recruits,* Military Medicine Volume 126, No. 4, 261-272, April 1961.

Molnar, G. W., *Survival of Hypothermia by Men Immersed in the Ocean,* Journal of the American Medical Association, 131: 1046-1050 (1946).

AFP 160-4-1, *The Etiology, Prevention, Diagnosis, and Treatment of Adverse Effects of Heat.*

Chapter 6

THE OTOLARYNGOLOGIC ASPECTS OF AEROSPACE MEDICINE

INTRODUCTION

Atmospheric pressure changes occur under a variety of conditions and circumstances. Military aircraft may ascend vertically faster than a mile a minute, maintain altitudes over 50,000 feet, and dive at speeds in excess of 10 miles a minute. If a parachute jumper delays opening his chute, he may attain a rate of descent approximating 10,000 feet per minute. Elevators in large office buildings ascend and descend at rates approaching 1,000 feet per minute. Day-to-day weather variations may produce pressure changes approximating a few hundred feet of ascent or descent.

When a cavity (such as a sinus) with a small opening to the exterior is moved through environments of different barometric pressures, equilibrium between the gas inside and outside the cavity will be established with a speed that will depend upon the size of the opening and the extent of change in pressure. This principle follows the laws of gaseous expansion and compression (Boyle's Law). The degree of expansion depends on the difference in density or pressure of the gas inside and outside a given chamber, and on the elasticity of the walls of the chamber.

Within limits, a closed expansible chamber, such as a rubber balloon, will vary in size as it ascends or descends until equilibrium of pressures is established. One volume of a dry gas at sea level becomes two volumes at 18,000 feet, three volumes at 28,000 feet, four volumes at 33,000 feet, and five volumes at 38,000 feet. On descent, the volume changes are reversed. When exposed to the flight environment, a rigid-walled cavity communicating with the outside is not expected to vary in size because pressure equilibrium will be established through its opening at all altitudes.

BAROTITIS MEDIA

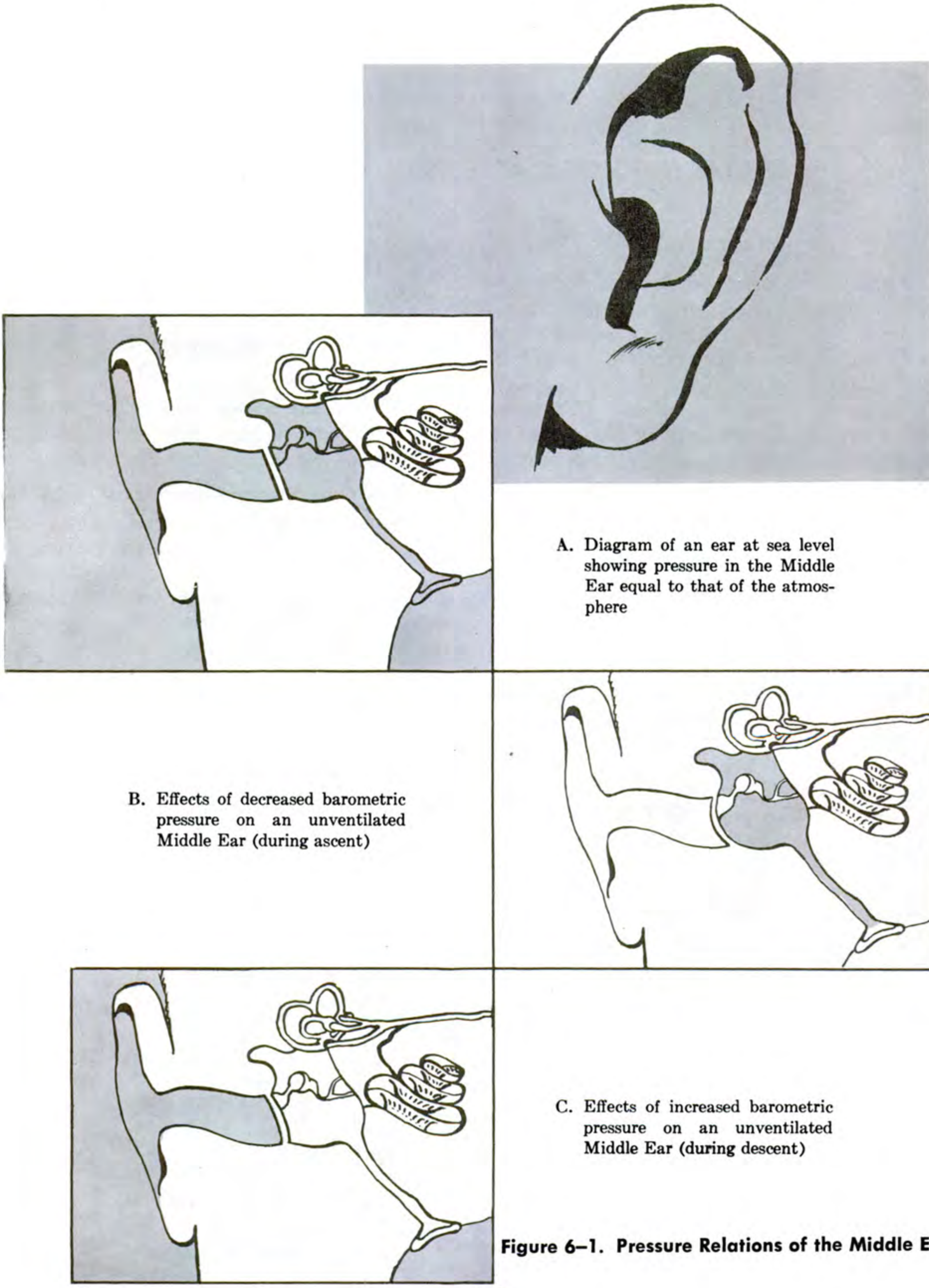
Barotitis media is an acute or chronic traumatic inflammation caused by pressure difference between the air in the middle ear and that of the surrounding atmosphere.

Structural Considerations—Anatomical

The middle ear is a membranous-lined, bony cavity, ventilated through the eustachian tube, with a thin, semielastic partition externally (tympanic membrane). The eustachian tube is a bony channel extending from the middle ear which unites with a membrano-cartilaginous channel extending from the nasopharynx. Normally, the tube is closed because of mucosal irregularities and cohesive mucosal surface. It reacts similar to a flutter valve and only opens via swallowing, yawning or yelling when the tensor and levator veli palatini muscles contract. The levator veli palatini arises partially from the medial lamina of cartilage of the auditory tube, and the tensor veli palatini arises partially from the lateral wall cartilage of the auditory tube. Consequently, when these muscles contract, they open the eustachian tube. Limited displacement of the tympanic membrane allows for some equalization of pressure, but this averages only 100 to 300 feet atmospheric pressure change.

Physiology

Ascent. From sea level to 110 to 180 feet altitude, 3 to 5 mm Hg pressure change occurs and produces slight fullness in the ear. The tympanic membrane bulges slightly and the pressure increases until 500 feet (15 mm



A. Diagram of an ear at sea level showing pressure in the Middle Ear equal to that of the atmosphere

B. Effects of decreased barometric pressure on an unventilated Middle Ear (during ascent)

C. Effects of increased barometric pressure on an unventilated Middle Ear (during descent)

Figure 6-1. Pressure Relations of the Middle Ear.

Hg pressure change) when a sudden "click" is heard and felt in the middle ear. At that time, the tympanic membrane snaps back to near normal as increased pressure in the middle ear forces air out. From that point on, the cycle is repeated with the exception that "clicks" occur at approximately 11.4 mm Hg (435 feet altitude). Eustachian tube opening requires approximately 15 mm Hg excess pressure at sea level. The tube remains open until pressure is reduced to 3.6 mm Hg when it again closes to retain 3.6 mm Hg (130 feet altitude) excess pressure in the middle ear. From then on, there is 11.4 mm Hg differential, but this decreases to 3.5 mm Hg at 40,000 feet. This can probably be explained on the basis of rarified or less dense air passing more readily through the eustachian tube. This is variable between individuals, but average figures for a given individual remain constant in multiple tests.

Descent. On descent, a totally different problem exists. The eustachian tube acts as a flutter valve and remains closed under all degrees of pressure (one subject tested to —470 mm Hg) unless actively opened by muscle effort or high positive pressures. Voluntary opening of the eustachian tube equalizes all pressure completely. However, after negative pressure of 80 to 90 mm Hg or more develops, it is unlikely that the eustachian tube muscles will overcome it and ascent is usually necessary to allow a patient to open the tube.

Etiology

Barotitis is usually the result of failure of ventilation of the middle ear on changing from low atmospheric pressure to high atmospheric pressure. A cold or upper respiratory infection is the most common cause. Swallowing normally occurs several times a minute during waking hours and once every 5 to 7 minutes during sleep, thus relieving or equalizing pressure. Failure to relieve pressure during a letdown from altitude may be due to ignorance or carelessness.

Pathology

Negative pressure in the middle ear (similar to application of a suction cup on soft tissue) results in a partial vacuum, vascular engorgement, and serosanguineous transudation and exudation into the tympanic cavity. This partially neutralizes pressure and leads to relief of tension on the collapsed eustachian tube. Pinpoint ecchymotic areas appear on the periphery of the tympanic membrane when hemorrhage by diapedesis occurs along the course of arteries of the malleus.

ACUTE BAROTITIS MEDIA

Acute barotitis media is an acute traumatic inflammation of the middle ear caused by pressure differences (either positive or negative) between the air in the middle ear and that of the surrounding atmosphere, and characterized by pain, deafness, tinnitus and, occasionally, vertigo.

Symptomatology

Ascent. A 3 to 5 mm Hg differential pressure is perceptible as a mild fullness in the ear; 10 to 15 mm Hg is perceptible as fullness, mild decrease in hearing and annoying discomfort; 15 to 30 mm Hg results in increased discomfort, possibly tinnitus, pain and mild vertigo; and over 30 mm Hg causes increased tinnitus, vertigo, and unbearable pain. Normally, 15 mm Hg pressure will force air out through the eustachian tube, thus relieving symptoms.

Descent. Pressure in the ear becomes relatively negative and is seldom relieved through its own force because of the flutter-valve-like action of the eustachian tube. At almost 60 mm Hg negative pressure, pain is severe and resembles that of acute otitis media. Tinnitus is marked and there is usually vertigo with the beginning of nausea. A 60 to 80 mm Hg negative pressure causes severe pain which radiates from the ear to the temporal region, the parotid gland and, occasionally, to the mastoid process. Deafness is marked, and vertigo and tinnitus usually increase. At a differential pressure of 100 to 500 mm Hg, the tympanic membrane ruptures, a loud sound is heard, and there is a sharp piercing pain, vertigo, nausea, and possibly collapse or generalized shock. After rupture, the pain decreases quickly and the nausea and vertigo subside. An 80 to 90 mm Hg differential pressure is usually impossible to overcome by muscular action, such as swallowing or performance of the Valsalva maneuver, and it is necessary to return to higher altitude to clear the ears. If trauma has occurred, opening the eustachian tube does not necessarily relieve all symptoms. Moderate trauma is followed by a sense of soreness in the ears and deafness lasting for several hours. Severe trauma is followed by pain, deafness, vertigo, and tinnitus for several days and perhaps up to 2 weeks.

Common signs in order of increasing severity are: a. Initially depressed tympanic membrane; b. inflamed tympanic membrane, pink-tinged or angry red; c. petechial hemorrhage; d. serous otitis media to hemotympanum; and e. perforation of the tympanic membrane.

Treatment

Swallowing, chewing gum, use of nasal vasoconstrictors, such as neo-synephrine, or performance of the Valsalva maneuver often proves effective, however, a return to higher altitude with gradual descent while performing the Valsalva maneuver should be accomplished if possible.

For a depressed tympanic membrane, myringotomy or politzerization should be done. Either the politzer bag or a source of compressed air may be used. For the bag method, the olive tip is placed in one nostril, the nose is compressed between the physician's fingers, and the patient is then instructed to swallow or say "kick, kick, kick, kick" while the bag is squeezed, increasing the pressure in the nasopharyngeal cavity. If compressed air is used, the pressure is turned down very low (beginning with 1 and never exceeding 6 pounds per square inch of pressure) and an olive tip, connected by a short hose to a bottle which, in turn, is connected through a thumb-operated valve to the compressor, is used. The nose and olive tip are compressed between the fingers, similar to the bag method, and the valve is closed by the thumb of the opposite hand. It may be necessary to increase the pressure gradually and carefully several times until air enters the middle ear via the eustachian tube.

For serous otitis media, politzerization usually helps very little. Myringotomy should be done only if the patient complains bitterly about deafness and stuffiness, since the serous otitis media will most likely recur after the drum heals.

For hemotympanum, treat conservatively.

For perforation of the tympanic membrane, treat conservatively; keep the ears dry and avoid local treatment.

RECURRENT BAROTITIS MEDIA

Recurrent barotitis media is a recurrent barotitis due to chronic eustachian tube obstruction, secondary to pathology in either the nose or nasopharynx.

Etiology

The most common causes of recurrent barotitis media are: Hypertrophied adenoids, allergic rhinitis, chronic granular pharyngitis, stenotic eustachian tube, Gerlach's tonsils, sinusitis, and deflected nasal septum.

Treatment

Treatment should be directed toward resolving the primary problem.

DELAYED BAROTITIS MEDIA

Delayed barotitis media occurs following the breathing of 100% oxygen for a time and refers to that condition in which an aircrewmember has no difficulty in ventilating his ears during flight, but develops signs and symptoms suggestive of acute barotitis several hours later. Personnel who fly in certain jet aircraft equipped with a system that delivers 100% oxygen, from the beginning to the end of the flight, are most prone to develop delayed barotitis. The condition occurs less frequently and symptoms are rarely severe in jet aircraft equipped with a diluter-demand oxygen system.

The victim of this condition usually terminates a flight in the late evening hours or during the night and is asymptomatic at that time. A short while later, he retires and is awakened in the early morning hours with a sensation of one or both ears being "stopped up" and frequently painful. Upon examination, the tympanic membrane appears the same as in acute barotitis media—retraction, hyperemia, and possibly fluid in the middle ear.

Physiology

The physiological mechanism involved in delayed barotitis media is assumed to be that of oxygen absorption from the middle ear. While the pilot is awake, he swallows several times a minute, and when asleep, he swallows once every 5 to 7 minutes. Thus, the eustachian tube opens more frequently during the waking hours and serves to equalize any negative pressure that may develop in the middle ear. With the infrequent swallowing associated with sleep, the negative pressure may become of such magnitude that the eustachian tube does not open during the swallowing maneuver.

The total pressure of gases in venous blood is 706 mm Hg. The partial pressure of oxygen in venous blood is 40 mm Hg. The partial pressure of 100% oxygen in the middle ear at sea level is approximately 760 mm Hg. Thus, there is partial pressure of oxygen in the middle ear about 54 mm Hg greater than in the venous blood. Only a few seconds are required for oxygen absorption to take place. As the oxygen is absorbed, the ambient atmospheric pressure of 760 mm Hg forces the tympanic membrane inward and thus, causes pain. Remember that not only the middle ear, but also the entire mastoid cellular structure is filled with 100% oxygen after breathing it for several hours.

CONCLUSION

Careful examination during the selection process will eliminate from flying many men who experience difficulty in ventilating the middle ear. Aircrewmembers should be taught the simple facts about cause, effect, and prevention of barotitis media. Exposure to marked barometric pressure changes should be avoided when the function of the eustachian tube is embarrassed to any degree. The Flight Surgeon's warning, "Do not fly when you have a cold or a sore throat!," is hard to get across when experience has taught us that many people can and do fly without sustaining discomfort in the ears. The loss of the services of an aircrewman for a few days, as the result of a severe cold, is far less detrimental to operational activities than the loss of his services for weeks or even months because of barotitis media.

The following principles of treatment are recommended:

a. Do not put anything in the external ear canal to relieve pain. It is not effective and makes examination of the tympanic membrane difficult.

b. Be conservative and keep in mind that the objective of your therapy is the restoration of the normal pressure gradient between the middle ear and ambient atmosphere.

c. Direct your therapy toward the nasopharynx and the eustachian tube.

d. Be gentle! The mucous membrane is delicate. Do not add to the existing trauma by rough handling.

e. Restore the middle ear physiology to normal as quickly as possible.

From these principles, it is obvious that treatment is essentially conservative. Acute symptoms may be relieved immediately with the voluntary opening of the eustachian tube in the act of swallowing or performance of the Valsalva maneuver. In cases where pressure has already produced trauma, introduction of air into the middle ear cavity will not necessarily relieve the symptoms of trauma; they may persist until recovery has taken place. Pressures that may be only uncomfortable at first may finally become painful. A safe and simple method for the rapid inflation of the middle ear is politzerization.

Aircrewmen should be placed on duty not involving flying while they have active barotitis media. Treatment of any conditions which predispose to development of barotitis is essential.

BAROSINUSITIS

Barosinusitis (sinusitis due to barotrauma) is an acute or chronic inflammation of one or more of the nasal accessory sinuses, caused by pressure differences (usually negative) between the air in the sinus cavity and that of the surrounding atmosphere. The condition is characterized by severe pain in the affected region.

Etiology

When the sinus is normal and the ostium is patent, free flow of air between the cavity and the exterior, resulting from a difference in pressure between the air in the sinus cavity and the surrounding atmosphere, brings about equilibrium during ascent and descent without sensation of change of structure (see figure 6–2). However, during the flow of air, several untoward events may occur. Fluid, mucus, pus or similar substances may enter the ostium, along with the air, as outside pressure is increased (see figure 6–3). Obstruction of the ostium by redundant tissue or anatomical deformities may prevent equalization of pressure (see figure 6–4). If blockage of the ostium by swollen tissues or anatomical deformities does occur, the relative pressure of the cavity is positive on ascent and negative on descent. Barosinusitis is usually frontal, but it can involve any of the sinuses.

Symptoms and Signs

The occurrence of pain with barosinusitis on ascent is far less frequent than on descent. The pain is severe and, in agreement with the accepted view of referred sinus pain, is usually localized in the frontal region. Local tenderness over the sinus is often present and persistent. A sucking noise high up in the nose is described by some patients and is often thought to be indicative of submucosal hemorrhage. Occasionally, a patient will exhibit lacrimation. Purulent and mucopurulent discharge will be seen in a great number of patients. Roentgenography gives the most reliable evidence of a sinus lesion (thickened lining, polyps, opacity) but does not clearly differentiate the contributory

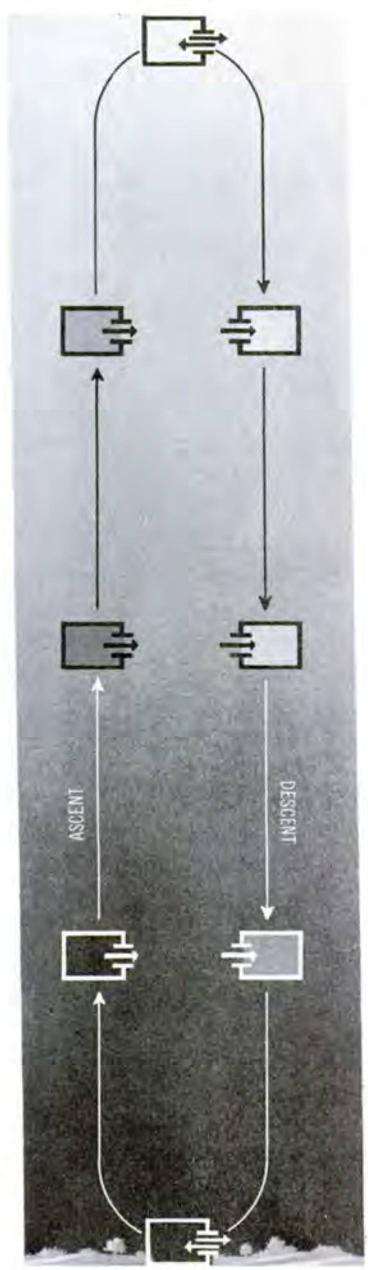


Figure 6–2. Barometric Adjustment Within the Sinus on Change of Altitude.

On ascent, adjustment of sinus pressure is made by escape of air from the sinus. On descent, adjustment of sinus pressure is made by entry of air into the sinus.

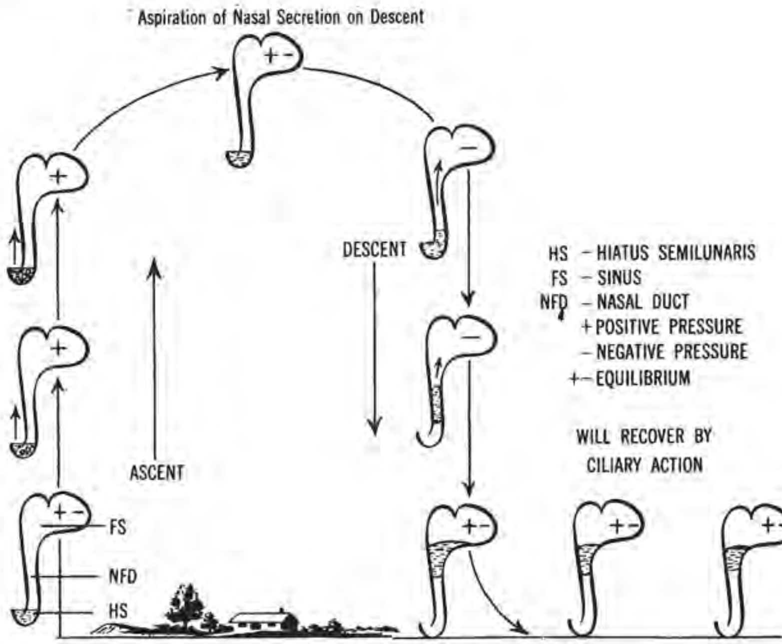


Figure 6–3. Frontal Sinus During Flight.

factors of preexisting disease or anatomical abnormality from the result of barotrauma.

Treatment

The immediate treatment of barosinusitis is reascent until the air pressure within the sinus is the same as that of the outside atmosphere. Subsequent descent should be as gradual as possible, thus affording every opportunity for pressure equilibrium to take place. In the treatment of barosinusitis, the following should be kept in mind: Time will cure a great percentage of the cases, but it is cruel to allow time to be the only therapy in your armamentarium. Barosinusitis is produced by mechanical blockage, and mechanical measures must be taken to overcome the condition. Thorough intranasal shrinkage is a must, with particular attention devoted to the areas beneath the middle turbinates. Analgesics should be employed if pain is severe. Systemic vasoconstrictors are necessary in addition to intranasal shrinkage. When shrinkage of the nasal mucosa by means of sprays and packs to the middle meatus is ineffective, the middle meatus should be anesthetized with a local anesthetic and the middle turbinate infracted. Normally, infraction is beyond the expected capabilities of the average Flight Surgeon and should be done by a qualified specialist except in the most unusual circumstances. The procedure for infraction consists of inserting a narrow instrument, such as a submucous elevator, into the anterior portion of the middle meatus and, with firm pressure toward the midline, fracturing the turbinate bone. It is necessary to fracture at least the anterior half of the middle turbinate and move it toward the midline since the ostia to the sinuses are located in this area. The goal of treatment is restoration of sinus physiology and equalization of pressure as quickly as possible. If conservative methods are ineffective, the maxillary sinus should be entered with a cannula through the natural ostium, or with a needle through the inferior meatus. If the attack is precipitated by the edema attending an infectious process in the upper respiratory tract, appropriate antibiotics should be employed in addition to the preceding measures. If the condition is not alleviated within 24 hours and the physician has reached the limit of his experience, the patient should be placed in the hands of the nearest otolaryngologist.

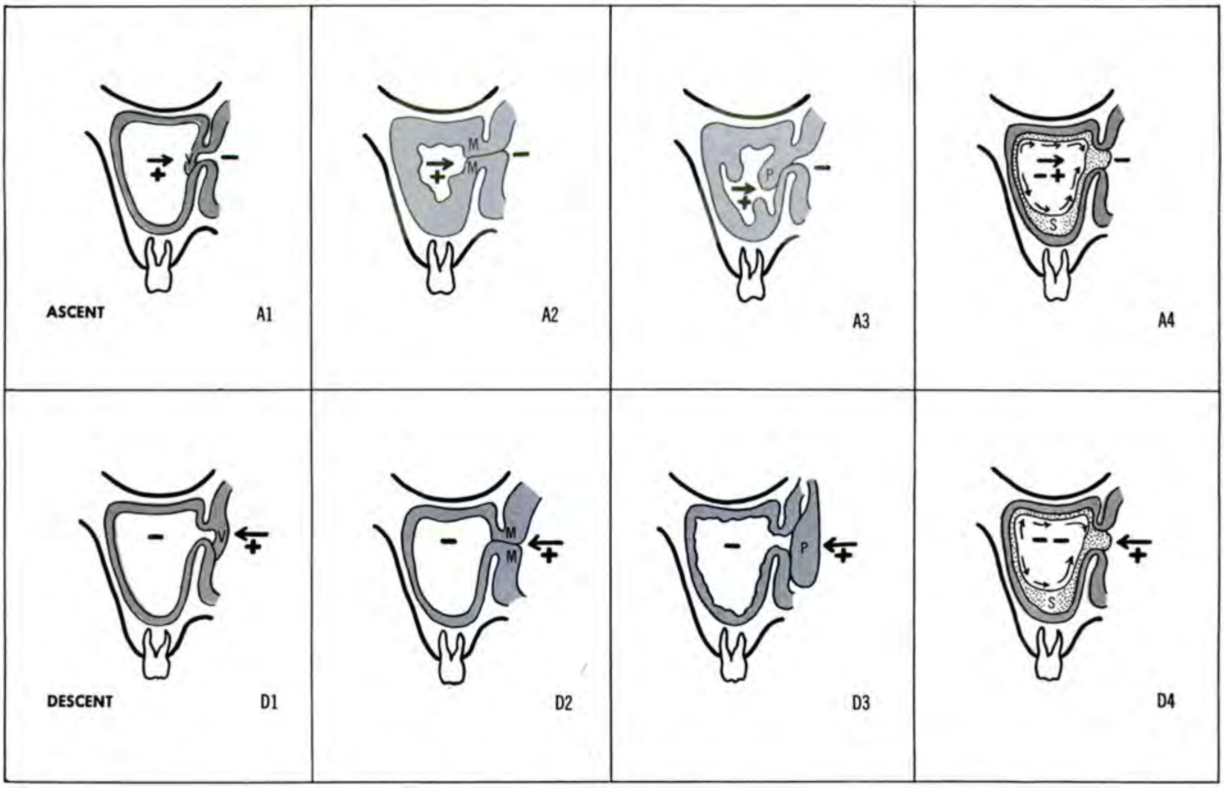


Figure 6-4. Occlusal Factors in Maxillary Antrum in Flight.

A. During ascent any valvular formation within the sinus cavity will prevent the exit of air from the sinus as the atmospheric pressure decreases. D. During descent and increase of atmospheric pressure similar formations on the nasal side of the ostium will prevent the entrance of air into the sinus. A. Ascent A 1. V—Developmental flap-valve formation of sinus mucous membrane. A 2. M—Swelling of the mucosa of sinus with flutter-valve effect. A 3. P—Mucosal polypus in sinus constituting a ball-valve. A 4. S—Effusion in sinus cavity acting as an exhaust-piston. D. Descent D 1. V—Developmental flap-valve formation of nasal mucous membrane with flutter-valve effect. D 3. P—Polypus presenting in nasal fossa and acting as a ball-valve. D 4. S—Effusion in sinus cavity with exhaust-piston effect. (Reproduced by the permission of Dickson, E. D. D., et al., Contributions to Aviation Otolaryngology, London, Headley Brothers, 1947.)

Prophylaxis

Primary conditions which affect the nose (septal deviation, allergy, polyps, infections) must be corrected before a candidate is qualified for flying. Temporary factors contributing to the blockage of the sinus ostia, such as an acute upper respiratory infection, are cause for grounding flying personnel until the condition has subsided. Should emergency conditions require flying when aircrewmen have an upper respiratory infection, nasal vasoconstrictors should be employed before ascent or descent.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., Aerotitis Media and Aerosinusitis, Chapter 11, *Aerospace Medicine*, Williams and Wilkins Co., Baltimore (1961).

Boies, Lawrence R., *Fundamentals of Otolaryngology*, 4th Edition, W. B. Saunders Co., Philadelphia (1964).

Bryan, W. T. K. and Bryan, M. P., *Cytologic Diagnosis in Otolaryngology*, Transactions.

American Academy of Ophthalmology 63:597-612 (September-October 1959).

Campbell, P. A., *Aerosinusitis—Its Cause, Course, and Treatment*, Annals of Otology, Rhinology and Laryngology. 53:291-301 (June 1944).

Coates, G. M., Schenck, H. P. and Miller, M. V., *Otolaryngology*, 5 volumes, W. F. Prior Co., Inc., Hagerstown Md. (1965).

Dickson, E. D., *et al: Contribution to Aviation Otolaryngology*, Headley Brothers, London (1947).

Dickson, E. D. and King, P. F., *Results of Treatment of Otitic and Sinus Barotrauma*, Journal of Aviation Medicine 27:92-99 (1956).

Eggston, A. A. and Wolff, D., *Histopathology of the Ear, Nose, and Throat*, The Williams and Wilkins Co. (1947).

Fowler, E. P., Jr., *Medicine of the Ear*, 2d Edition, Thos. Nelson and Sons, New York (1947).

German Aviation Medicine—World War II, Volumes I and II, Prepared Under the Auspices of the Surgeon General, US Air Force (1950).

Greene, R., *An Aviator and His Ears*, Industrial Medicine 7:669-671 (Nov 1938).

Guthrie, D., *Diseases of the Nose, Throat, and Ear*, 5th Edition, The Williams and Wilkins Co., Baltimore (1952).

Jackson, C. and Jackson, C. L., *Diseases of the Nose, Throat and Ear*, 2d Edition, W. B. Saunders Co., Philadelphia (1959).

Kopetzky, S. J., *Deafness, Tinnitus and Vertigo*, Thomas Nelson and Sons, New York (1948).

Kraus, R. N., *Sinus Barotrauma—Treatment*, USAF School of Aerospace Medicine Review 1-59 (October 1958).

Lederer, Francis L., *Diseases of Ear, Nose, and Throat*, 6th Edition, F. A. Davis Co. (1952).

McKenzie, William, *Ear Nose, and Throat Diseases*, E. and S. Livingstone, Ltd, Edinburgh and London (1953).

Morrison, W. W., *Diseases of the Ear, Nose and Throat*, 2d Edition, Appleton-Century-Crofts, Inc., New York (1955).

Ogden, F. W., *Politzerization, A Simple and Effective Method in Treatment of the Aerotitis Media*, Air Surgeon's Bulletin I:18-20 (April 1944).

Portmann, G., *Diseases of the Ear, Nose and Throat*, Williams and Wilkins Co., Baltimore (1951).

Senturia, B. H., *Allergic Manifestations in Otologic Disease*, Laryngoscope 70:287-297 (1960).

Chapter 7

AEROSPACE SYSTEM NOISE

Most persons associated with the operation of military aerospace systems undergo hazardous noise exposures at one time or another. Air Force-wide adoption of turbojet, turboprop, and turbofan-powered aircraft has necessitated special attention to the hazardous noise environment of men working on and near aircraft on the ground, and to the use of land (*i.e.*, hospitals, residences) adjacent to airfields. The operation of missiles and the coming of manned space systems have added other noise environments of concern. Despite the fact that aerospace crew members still are exposed to high-intensity noise levels, it is the ground maintenance and control personnel who are subjected to the most hazardous noise exposure in terms of sound pressure level, duration or both.

The Flight Surgeon must familiarize himself with the noise conditions prevalent in the operations of his particular installation, and he must maintain a constant program of prophylaxis if he is to prevent ill effects among his men. AFR 160-3 provides for the:

a. Indoctrination of personnel on the undesirable effects of noise.

b. Designation and surveillance of hazardous noise areas.

c. Issuance of personal protective devices and instructions on their care and use.

d. Reduction of exposure of personnel to intense noise in work areas.

e. Monitoring of audiometry.

THE EFFECTS OF NOISE ON MAN

Noise, in itself, is of little importance unless it adversely affects a receiver—a man, a structure, or the like. The effects of noise on man fall into three categories:

a. Noise that may be a source of annoyance and irritability.

b. Noise that may interfere with voice communication and other types of auditory signals.

c. Noise that may be of sufficient intensity and duration to have a potential temporary or permanent damaging effect on the hearing of an individual.

Generally, with an increase in noise intensity, there are five thresholds of interference involving human functions which should be considered. These are discussed below in the order of increasing intensity:

(1) *Interference With the Threshold of Hearing*. This occurs at very low noise levels as the threshold of hearing is the lowest level at which a sound can be detected.

(2) *Interference With Rest and Sleep*. This may occur on an air base or in adjacent communities. At equal intensity levels, low frequency noise creates less subjective interference than mid- and high-frequency noise. A continuous noise is less irritating than an intermittent noise. Subjective tolerance is also a factor in that persons accustomed to the presence of a noise are less adversely influenced than those unfamiliar with its presence. AFM 86-5 presents a procedure for estimating exposure to engine noise from ground and flight operations of military and civilian jet and propeller aircraft, and for relating the estimated exposure to the expected response of on and off-base residential communities.

(3) *Interference with Auditory Communciation*. The degree of this interference is dependent upon the relative frequencies and strengths of the primary signal and the noise. There are several thresholds for communication, depending upon the quality of

the information required for effective operation.

(4) *Threshold of Hearing Damage Risk.* This refers to noises which can produce a hearing loss after varying periods of exposure. Although permanent hearing loss may not result, temporary threshold shift and tinnitus are likely. The Damage Risk Criterion graph (figure 7-1) shows the best estimate of threshold hazardous sound pressure levels in each of the eight frequency bands between 37.5 and 9,600 cycles per second (cps) for continuous wide-band noise. If these sound pressure levels are exceeded continuously for an 8-hour day, 5 days a week, during a 25-year working lifetime, they will give rise to a risk of permanently impaired hearing for an unprotected ear. However, these levels can be exceeded with comparative safety for noise exposures of shorter duration, or when ear protection is used to reduce the effective exposure.

(5) *Threshold of Aural Pain.* Since pain is considered a sign of physiological damage, the noise level in the ear canal should never exceed this threshold, no matter how short the exposure period. A person's exposure to noise above this level may result in nonauditory effects such as disorientation, nausea, and vomiting, even if the ear canal is protected.

Noise-Induced Hearing Loss

The susceptibility to noise-induced hearing damage varies among people. Some appear to have *tough* ears and can tolerate higher noise levels better than those with *tender* ears. At present, there is no way of identifying tender ears prior to the individual's exposure to noise. It is known that noise can be harmful or detrimental to the hearing of man even though it is not painful to the ear. In fact, there are no pain fibers within the inner ear to warn of impending injury. Therefore, if the damage risk criterion is exceeded, ear protection should be worn. The damage risk criterion represents a conservative standard and, if not exceeded continuously, should prove to be safe for the majority of individuals who are routinely exposed to noise.

Description of Hearing Loss

When the muscles of the middle ear, whose function it is to attenuate high-intensity noise, and the sensory cells and nerve fibers of the inner ear become fatigued, the inner ear may be damaged. In cases of extreme impact noise or blast, the tympanic membrane is ruptured and the ossicles may be dislocated. The degree of damage to any individual ear is dependent upon the intensity, duration, and type of stimulation. The differences is susceptibility and in capacity to recover are very great among individuals. Some ears will be damaged temporarily by exposure to noise levels as low as 90 db for short periods; others will withstand intensities of 120 db for relatively long periods. Also, some persons will recover from a given degree of loss suffered from noise exposure in a few minutes while others will require a full day or longer.

Severe depressions in auditory acuity can be suffered without danger of permanent impairment if sufficient time is allowed for recovery before the next exposure. Such hearing losses are termed *temporary* threshold shifts. Persons who require a longer recovery process, and who work in occupations that generate noise continuously, may not be afforded sufficient time for complete recovery between exposures. This results in a daily accumulation of hearing loss. Unless

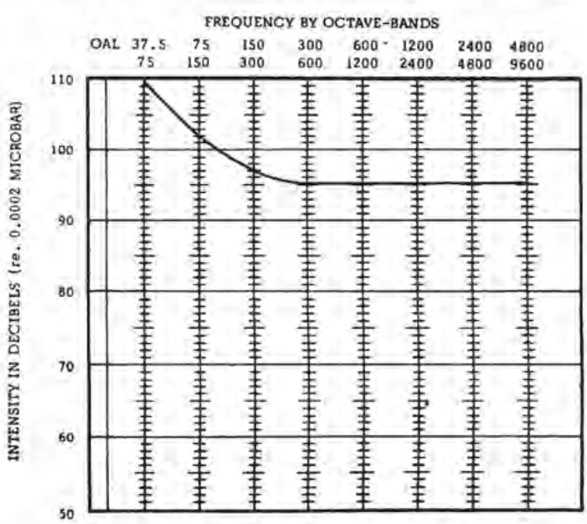


Figure 7-1. Damage Risk Criterion.

they are removed from the job or are equipped with adequate ear protection, their ears do not recover appreciably even with longer time allowances. Their hearing losses may then be termed *permanent.*

Although the temporary deafness suffered may involve the lower and middle frequency ranges, the permanent impairments more often center around the frequency of 4,000 cps. The low point of impairments most commonly recognized is from 3,000 to 6,000 cps. A typical progression is one in which the damage is first confined to a narrow frequency band. With further exposure, the impairment spreads to the surrounding frequency bands, and the initial low point goes lower. The losses are perceptive in character. (Conduction loss is superimposed when the middle ear is also injured.) Those in whom the loss is centered about 4,000 cps may suffer quite extensive impairment in the high frequencies before hearing in the speech range is affected. Figure 7-2 depicts progressive audiograms showing a typical regression of hearing acuity resulting from prolonged exposure to severely hazardous noise.

Incidence of Noise-Induced Hearing Loss

In assessing the effects of noise on the auditory acuity of a group of people, it should be remembered that, among the so-called normal population, there are many

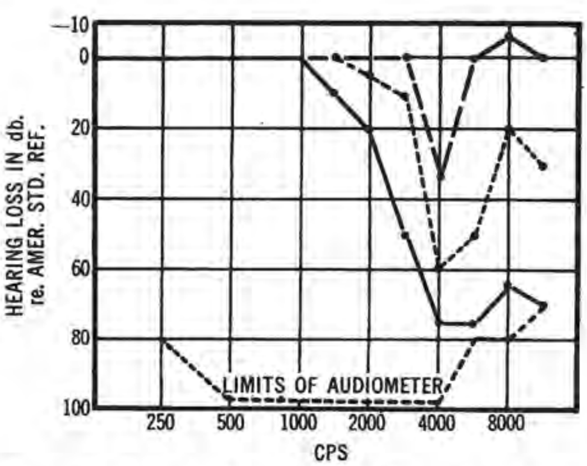


Figure 7-2. Typical Regression of Hearing Acuity Resulting From Prolonged Exposure to Hazardous Noise.

cases of high-tone perceptive hearing loss which cannot be attributed to noise. Approximately 20% of normal young men exhibit an impairment of some degree in the frequencies above 2,000 cps. Furthermore, the average person gradually loses acuity for the high frequencies with age. By computing the percentage of such losses among men working in noisy occupations and comparing it with that among the general population, it has been demonstrated that the proportion of such impairments is higher with longer exposure to more intense noise. On the other hand, in even the noisiest areas, there have been persons who have retained perfect hearing acuity.

There are many occupations in the Air Force today which of necessity involve potentially hazardous noise exposures. The degree of hazard is dependent upon the sound pressure level and frequency composition of the noise, the duration of the noise exposures and the intervening "quiet" periods, and upon the susceptibility of the individual ears. The occupations range from flight crew through the various ground maintenance areas, to shop, armament, and missile activities. Although adequate preventive measures have been developed for each occupation, noise-induced hearing losses continue to show up among some members of all occupations.

It is also imperative to recognize the potential hazard that noise represents to persons in housing areas in proximity to the noise source.

Tinnitus

The temporary deafness incurred by noise is frequently accompanied by a feeling of "fullness" and a ringing, buzzing or roaring sound (tinnitus) in the ears. Such sounds will subside for most persons within a few minutes, but will continue with others over a period of many hours. A few people perceive one of these types of noise almost constantly. Although there are many factors which can and do cause tinnitus, those cases which follow exposure to noise are thought to be indicative of a direct irritation of the nerve and/or the sensory cells by the noise. Many persons who have permanent impairments in the middle or high frequency range experience fairly constant tinnitus. People with normal hearing acuity rarely suffer from tinnitus except immediately after noise exposures.

Effect of Noise on Speech Perception

In the past, it was thought that the temporary depression in acuity resulting from noise exposures would affect perception for spee.. during such exposures. The assumption was that a man who displayed very definite speech impairment under quiet circumstances following a long flight would, likewise, have experienced difficulty in perceiving signals over his radio during the latter portion of his flight. It was demonstrated, however, that such was not the case with most men. Although there is definite impairment for signals of low intensity, there may be little or no impairment of ability to perceive signals of high intensity. Hearing acuity is "recruited" as sound pressure level of the signal rises. Because of the high signal intensities required in flight by normal ears for adequate perception of signals, the acuity of ears which have been fatigued is therefore adequate. The situation is similar for people employed on the ground in areas where noise is intense. This phenomenon prevails for many, although not for all persons demonstrating permanent perceptive lesions.

Nonauditory Effects

Among the general effects of noise, the most universal is a feeling of excessive fatigue at the end of exposures which is out of proportion to the fatigue that would be expected from similar work under quieter circumstances. Both fliers and ground maintenance men have noted this effect to be greater at higher noise levels. With respect to the fliers, it appears likely that a portion of the fatigue can be attributed to the necessity for paying strict attention to the radio signals, especially during instrument flight. Although the signals usually do not add to the total noise, the signal-to-noise ratio (difference in intensity between signal and ambient noise) is very small when compared with that in normal ground communication. There is, then, a psychological strain involved in the listening. As for the ground maintenance men, the noise alone appears to be responsible, the noise of jets being relatively more fatiguing than that of piston engines.

There is, frequently, an increase in irritability connected with generalized fatigue. This effect has been noted by men working on jet aircraft. If proper ear protection and ear protector-communication devices are worn, the fatigue factor can be decreased significantly.

There are great differences among people with respect to the degree of nonauditory effects developed. This degree varies from time to time in the same person, depending upon his general physical and emotional condition. Little correlation has been found between auditory acuity and nonauditory responses, but emotional stability appears to be a significant factor here. There is a very definite correlation with the spectrum of a noise. Low-pitched noise is far less disturbing to most individuals than the equally intense sound of medium pitch. Very high-pitched noises are annoying to most persons at any level. Narrow-band or pure-tone components magnify the annoyance for all frequency ranges.

In some instances, complaints of nonauditory response are so vague as to suggest malingering. The person cannot put his finger on any one symptom; he just does not like the noise. In other cases, specific symptoms are described. There is acute pain in the ears if no protection is worn. Regardless of ear protection, there is a feeling of overall pressure or blast. The nasal cavities, chest and abdomen are felt to vibrate in response to the sound. Vestibular reactions are sometimes evoked; unsteadiness and occasional nausea and vomiting occur. Weakness in the knees has been noted in some cases, and visual disturbances have been observed. All of the latter symptoms disappear with cessation of the noise.

Clinical Experience

Considerable data concerning the effects of noise on man has been obtained during the past few years. As mentioned previously, excessive fatigue and somatic symptoms occur infrequently among persons using adequate ear protection. When these symptoms do occur, they are almost invariably associated with the assignment of a new type of aircraft or engine at the base. There appears to be little, if any, consistent relationship between the noise intensity and the reporting of these symptoms. After a new aircraft or engine has been operating on a base for several months and experience is gained in its operation, the reports of excessive fatigue and other somatic complaints seemingly disappear. For this reason, it is suspected that, often, symptoms may be more psychological than physiological in nature.

Effect on Work Output

Among those who are able to adapt to and protect their ears from noise, there is apparently no change in work output, either qualitatively or quantitatively. It is not possible to assess the precise effect on work of those who continue to object to noise. The difficulty of concentration and the desire for the noise to cease are thought to combine so that work is performed hurriedly and with less attention to accuracy by these persons. The increase in fatigue and in general irritability must also be assumed to affect performance of duties.

Influence of Ultrasonics

During early experimentation on jet and rocket engines, observation of the symptoms outlined above led many to believe that there might be very intense ultrasonic frequencies (those above 20,000 cps) included in the acoustic energy which were responsible for the effects. A number of investigations were carried out which resulted in the following determination: *There is no reason to fear damage from ultrasonic energy generated by jet and rocket engines* for the following reasons:

a. The ultrasonic frequencies present in the vibration spectrum generated by jet engines are far less intense than those within the sonic range. They seldom exceed 120 db at 20,000 cps and fall off in intensity rapidly with increase in frequency. The noise spectra of the newer and more powerful engines tend to include progressively less energy above the sonic range as they include more in the very low frequencies.

b. Small fur-bearing animals can be killed by exposure to ultrasound in the range of 150 db, but *not* by the lower intensities of ultrasound present in jet noise spectra.

c. These small furred animals absorb a fairly high proportion of ultrasonic energy while absorption of high-frequency energy by human skin is relatively very poor. The small animals are not able to dissipate the heat generated in absorption while the human organism has an efficient system for regulating heat. Therefore, even 150 db of ultrasound would have little serious effect on a human.

d. Experiments using pure tones of low frequency and bands of noise covering *only* the sonic range have shown that somatic and mental symptoms, identical to those experienced upon exposure to jet noise, can be aroused by very high intensities of sonic energy. The problem is one of high intensity rather than high frequency.

e. Personal ear protectors attenuate ultrasound very effectively.

Air Force personnel who work on jet or rocket aircraft continue to be plagued by occasional rumors to the effect that all personnel will suffer various dire consequences following exposure to "supersonics." (The commercial airlines experienced similar rumors during the early days of the jetliner.) The Flight Surgeon should keep the above points in mind and be prepared to ward off serious morale situations.

NOISE IN FLIGHT

The types of noise generated at the ear level of crew and passengers during flight are varied. The following are significant contributors to internal noise:

a. Basic power plants such as reciprocal, turbojet, turbofan and turboprop.

b. Rotating propellers and rotors.

c. Aerodynamic friction and boundary-layer disturbances.

d. Airflow and airducting from air-conditioning and ram air systems.

e. Secondary auxiliary power units that are located inside or attached to the main fuselage.

f. Communication system noise such as electrical static, background noise, and extraneous secondary signal noise.

Reciprocating Engine-Powered Aircraft

A fixed-wing, reciprocal engine-powered aircraft generates intense low frequency-type noise. The primary noise emanates from the rotating propeller tips and is greatest in the plane of the propeller. It is characteristically low frequency and increases in magnitude as the RPM increases. The fundamental frequency of propeller-type noise is usually below 300 cps and is rich in higher harmonics. The noise generated by the engine exhausts is higher in frequency, but usually less intense. Figure 7-3 shows the noise spectrum in the propeller plane of a C-119C aircraft during various phases of operation.

The noise generated by the propellers during rotation is dependent upon several factors, namely, the number of blades, shape of the blade and blade tips, chord size, propeller diameter, blade pitch, and RPM. During flight, internal positions nearest the prop plane are usually the stations where the most intense noise is experienced. The audible spectrum produced within the crew compartment of single-engine aircraft is usually a mixture of propeller, exhaust, and structurally induced noise. The noise produced at various station positions in multiengine aircraft varies with the location of the propeller plane in relation to the general over-all design of the aircraft. Dual-engine aircraft are usually designed in such a manner that the propeller plane is closer to the pilot compartment than is the propeller plane of four or more engine-aircraft where the wing is set back at a greater distance.

Noise from the exhaust of large reciprocating engines may be quite intense. The contribution of the exhaust to the total noise

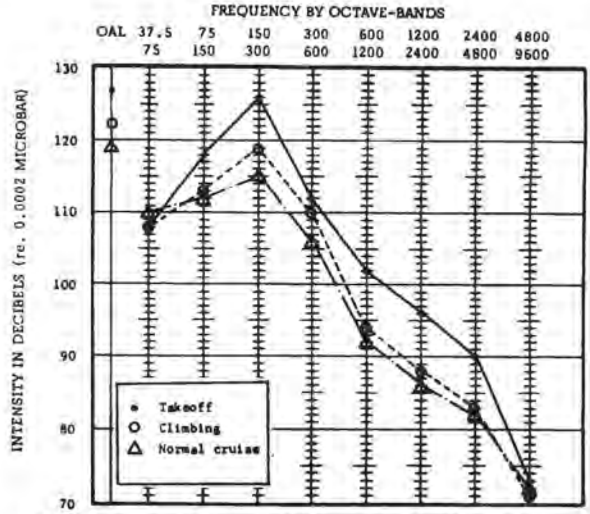


Figure 7-3. Internal Noise at Propeller Plane of C-119C.

exposure varies with the location of the observer in relation to the exhaust ports. If the exhausts are positioned so that the noise emitted from them is not blocked by the wing or other structures, it will be more intense at crew stations, both laterally and aft of the exhaust port openings.

Aerodynamic friction is usually not a significant contributor to internal noise because indicated airspeeds are relatively low, but the passage of air over seals at doors, windows, and hatches can produce a significant increase in the mid and higher frequency noise at crew or passenger stations near them.

Turbojet and Turbofan-Powered Aircraft

Noise experienced at crew stations within a turbojet or turbofan-powered aircraft originates from two principal sources: engines and aerodynamic friction. During ground runup, taxi, and takeoff, the engines are the primary contributors; as airspeed increases, the presence of aerodynamic noise becomes more dominant. When aircraft engines are installed internally or semi-externally in the main fuselage, engine noise may be propagated by direct structural vibration.

In turbojet and turbofan aircraft, aerodynamic noise increases as the airspeed increases, and at high speeds, it is considerably more noticeable than the engine noise. The noise spectrum measured in the rear seat of a T–38A, as shown in Figure 7–4, illustrates the influence of increased airspeed on aerodynamic noise. This noise increases progressively in the frequency bands above 150 cps.

Noise within bomber, cargo, and tanker-type jet aircraft varies with station positions. Aerodynamic noise is predominant in areas forward of the wing, especially in the cockpit. Station positions aft of the wing

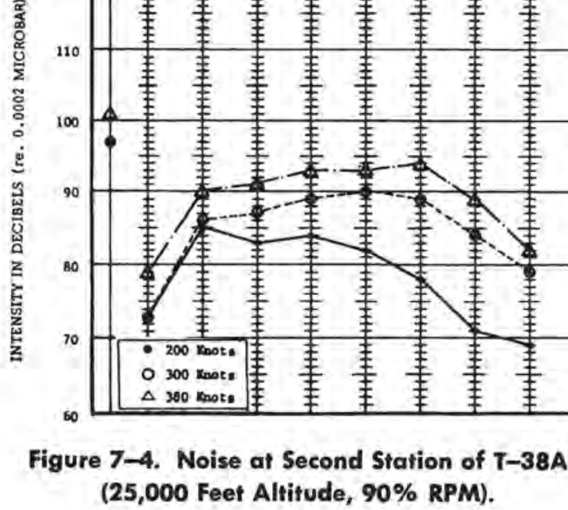


Figure 7–4. Noise at Second Station of T–38A (25,000 Feet Altitude, 90% RPM).

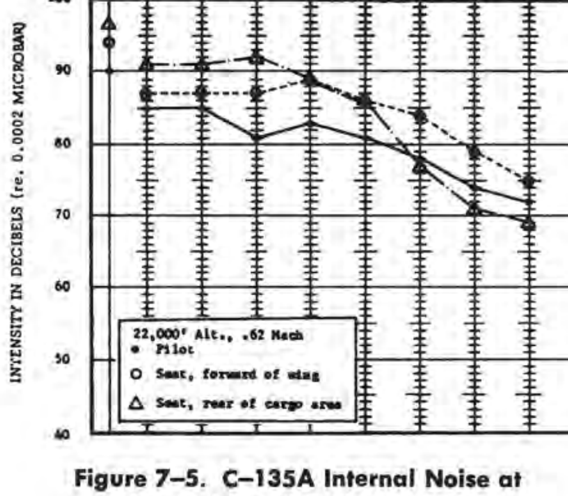


Figure 7–5. C–135A Internal Noise at Normal Rated Cruise Power.

usually contain the most intense noise radiated by the engine exhausts. Compared to propeller-driven aircraft, relatively little acoustically induced structural vibration contributes to the total noise level. Figure 7–5 illustrates noise levels at different positions in a C–135A flying at maximum continuous cruise power.

From the viewpoint of noise, the introduction of turbofan versions of basic turbojet engines offers an advantage. There is significantly less noise from the exhaust for the same or greater thrust rating. The turbofan-type engine is presently used in fighter, bomber, cargo-transport, and cargo-tanker aircraft, including the F–111, A–7, B–52H, C–135B, C–141A, and KC–135B. Figure 7–6 shows a comparison of the noise generated at comparable crew stations in a C–135A (turbojet) and a C–135B (turbofan). As can be seen, the high frequency whine of neither engine is outstanding. This is primarily due to the good attenuation of high frequency noise by the fuselage.

Many high performance turbojet and turbofan-powered aircraft employ air or dive brakes. These brakes, when deployed, may significantly increase the level of internal noise. Figure 7–7 illustrates the change in noise within the passenger compartment of a T–39A when the air brakes are extended.

Turbojet and turbofan engines do not require a runup prior to takeoff as do propeller engines. Therefore, intense noise generated at ground level with high power settings is present only during actual takeoff.

Turboprop-Powered Aircraft

The noise levels in turboprop-powered aircraft are not unlike the levels and spectrum of conventional reciprocating engine-aircraft. Characteristic of the noise within the aircraft is the low frequency energy emanating from the rotating propeller tips. Figure 7–8 shows an octave band spectrum level curve for the C–130B aircraft for two flight conditions inside the flight compartment. The octave band levels for other turboprop aircraft vary somewhat, but the general shape of the noise curves are similar.

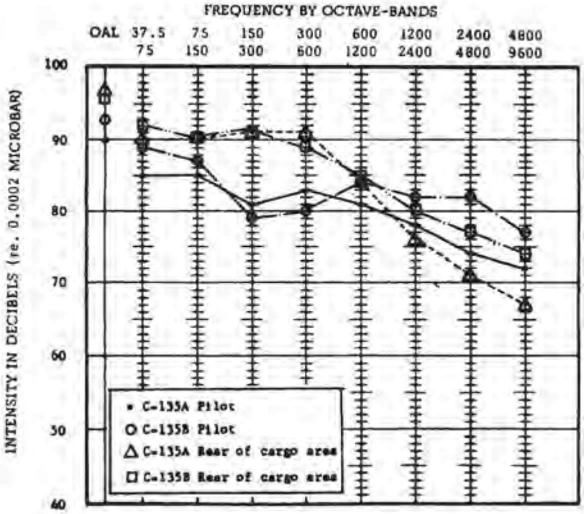


Figure 7–6. Noise Comparisons in C–135A and C–135B at Comparable Crew Stations, Normal Rated Cruise Power.

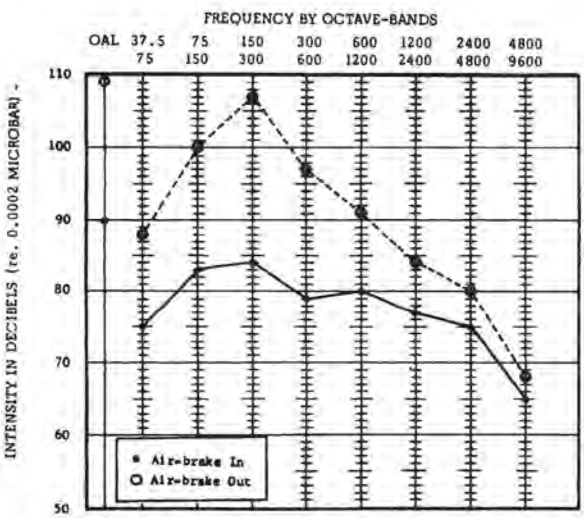


Figure 7–7. T–39A Dive Brake Noise.

Internal Auxiliary Power Units

Many cargo and tanker-type aircraft use an AC, DC, or a combination AC-DC auxiliary power unit which is located within the main fuselage or in a semi-external pod. These units usually are powered by a reciprocal or gas turbine engine, with the exception of the C–133, and operate only during ground checkout, loading and unloading, and just prior to landing. Figure 7–9 shows some noise measurements made near these units while they were operating. If these units are to be kept in operation for any length of time, the flight crew working around them should be advised to wear ear protection.

Helicopter Noise

Many rotary wing aircraft create considerable noise and vibration. Sources of this noise and vibration are the power plant, transmission, exhaust, and rotors. Noise produced by the impacting and shearing motion of the gears within the transmission and

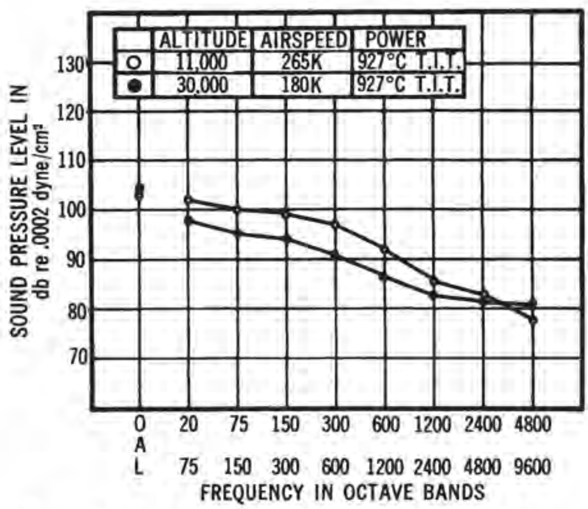


Figure 7–8. C–130B Flight Compartment Noise Levels in Flight.

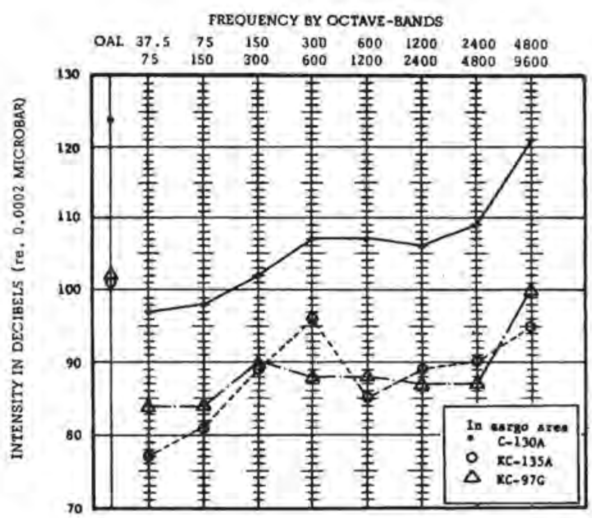


Figure 7–9. Measurements at Operator Position of Internal Auxiliary Power Units.

gear boxes exists on almost all military-type helicopters. Reciprocating engines, especially large ones, produce intense exhaust noise below 400 cps. Little exhaust noise is associated with helicopters powered by jet engines, but in some instances, objectionable high frequency noise may be produced by the compressor stages of the engine. The rotors are responsible primarily for low frequency noise which increases with the speed of rotation. Structural vibration and resonance may also raise the internal noise level. Figure 7–10 illustrates the noise measured at the pilot position in three types of helicopters.

NOISE DURING GROUND OPERATIONS

Ground maintenance and other ground crew personnel are exposed to the most intense noise associated with aircraft operations. This is especially true of engine maintenance personnel. The following sections discuss the major sources of this noise.

Ground Power Units

Many types of ground power units are used by maintenance and ground crew personnel. Some of the more important types include:

a. AC, DC, or AC–DC auxiliary electrical power units.

b. Gas turbines which provide highly compressed air for starting reaction-type engines.

c. Air-conditioning and heating units.

In many instances, the ground crew personnel may be exposed to hazardous noise from these ground power units. Personnel working around such equipment should be encouraged to wear proper ear protection.

Reciprocating Engine-Powered Aircraft

Reciprocating engine noise is a discontinuous noise having a low fundamental frequency and a gradual falling off of energy at higher frequencies. As illustrated earlier, crews flying reciprocating engine aircraft receive little exposure to high frequency noise because of this feature and the attenuating effect of the fuselage. However, considerable high frequency noise is present in the spectrum reaching ground personnel since they are outside the aircraft. Figure 7–11 shows the noise levels measured at various angular positions at a distance of 200 feet on the left side of a C–124A aircraft during a ground runup of engines one and two at takeoff power, with engines three and four at idle power. The most intense noise was found 80 through 120 degrees from the nose of the aircraft.

Turbojet and Turbofan-Powered Aircraft

The noise of jet engines operating on the ground is continuous and of a high intensity level throughout the audible frequency range. Noise levels of 110 to 120 db are very common even at relatively low power settings, both at the locations where men work on jet aircraft and over a fairly wide area surrounding the aircraft. Toward the rear of the engines at high power settings, the noise often exceeds 130 db.

Turbojet and turbofan engines have certain characteristics which are seemingly common to any reaction-type engine. Some of these characteristics are as follows:

a. Of the total power generated by a reaction-type engine, only a small portion is in the form of acoustic energy.

b. The most intense acoustic energy is propagated at an angle of about 10 to 45 degrees to the front of the engine and about 15 to 35 degrees to the rear of the engine.

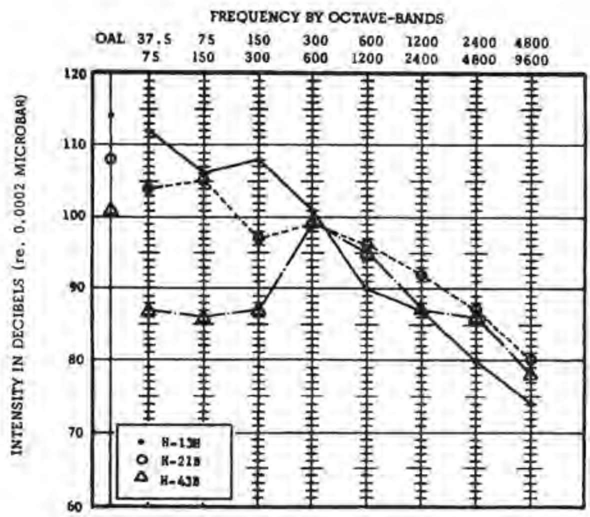


Figure 7–10. Measurements at Pilot Positions in Three Types of Helicopters at Normal Cruise.

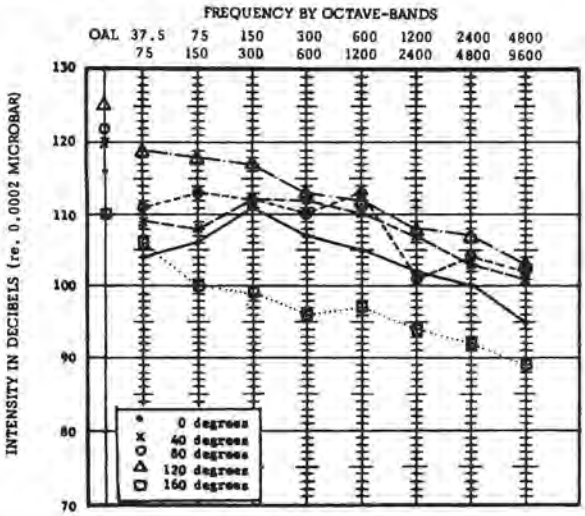


Figure 7-11. C-124 Ground Runup Noise at a Distance of 200 Feet, With Engines One and Two at Takeoff Power, and Engines Three and Four at Idle Power.

Very great differences in noise level are found at locations only a few feet apart.

c. At high power settings (military power and augmented power), the most intense acoustic energy is distributed near the exhaust plane.

d. The greater the thrust of an engine, the lower will be the frequency range containing the most intense acoustic energy.

This shift in maximum acoustic energy with increased thrust can be seen in figures 7-12 and 7-13. Figure 7-12 shows the noise spectrum of a J-57 engine at approximately 10,200 pounds of thrust while figure 7-13 illustrates the noise spectrum of a TF-33 engine operating at about 17,000 pounds of thrust. A comparison of the two illustrates the difference in level of exhaust noise generated by turbojet and turbofan engines.

One point of note with regard to maintenance of the jet engine and that of the reciprocating engine is that it is often necessary to work on the jet engine while it is operating, but this is seldom necessary or possible in the case of the reciprocating engine. One of the more common maintenance jobs around turbojet engines is the fuel flow adjustment, which is accomplished while the engine is operating at various power settings. Noise levels encountered by personnel performing this operation are shown in figure 7-14. It is readily apparent from this graph that mechanics exposed to these noise levels should wear combination protection of *plugs and muffs*.

Turboprop-Powered Aircraft

The turboprop engine may produce intense noise exposures for ground crew personnel since the propellers rotate at high RPM regardless of the phase of ground runup. Figure 7-15 shows the noise environment generated at maintenance positions near the propeller plane of a C-133A operating at 80% of normal rated power.

The C-130, C-133, and C-141 cargo aircraft have gas turbine auxiliary power units installed in the left-hand gear pods. These units may operate for long periods while the aircraft is on the ground. Figure 7-16 shows that the noise produced is rich in intense high frequency components near the intakes of the auxiliary power units; however, the levels are less severe at the loading ramp where most personnel must be.

PROTECTION AGAINST NOISE

There are three approaches to the problem of protecting personnel against noise: a. The reduction of noise at its source; b. the reduc-

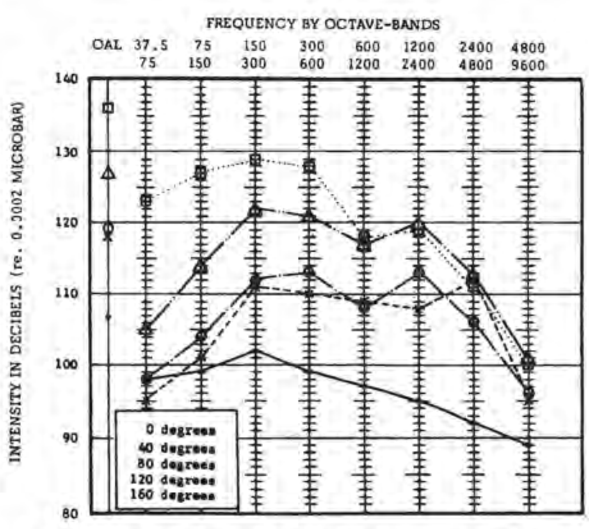


Figure 7-12. Turbojet Engine Noise at 100 Feet, Military Power.

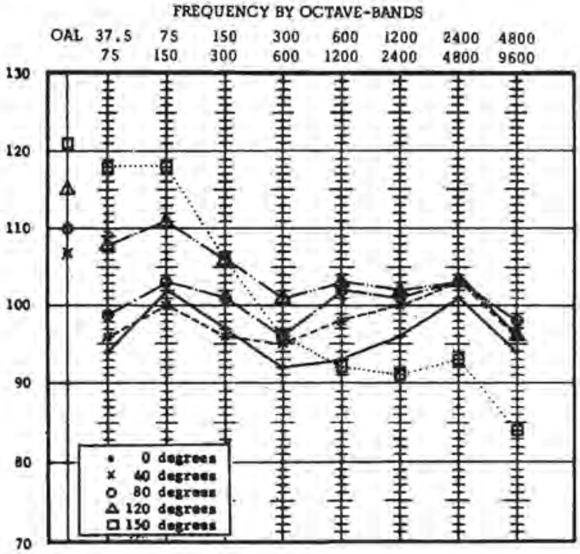


Figure 7–13. Turbofan Engine Noise at 150 Feet, Maximum Takeoff Power.

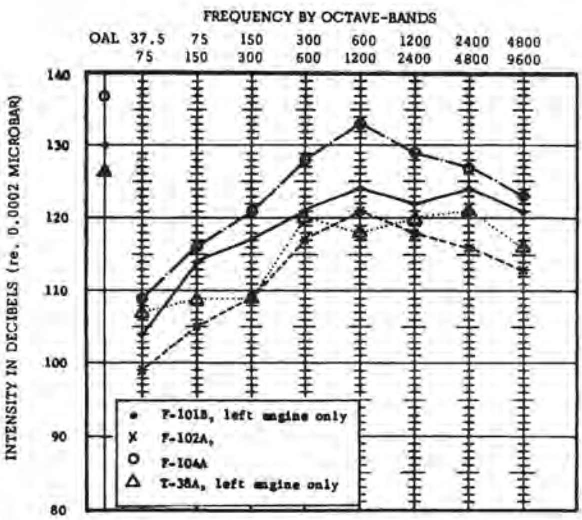


Figure 7–14. Engine Trim Noise Exposures, Military Power.

tion of exposure durations; and c. the provision of personal protective measures. With reference to the first two, the Flight Surgeon can and should keep himself informed of the noise situation on his base by frequent inspections of the flightline area. He can often make recommendations for moving aircraft farther from hangars and placing them in such a way that the worst noise is aimed away from inhabited areas during engine runups. In some cases, he may be able to initiate changes in procedure which will result in fewer individuals being required to stay in the immediate vicinity of aircraft during runups, and in lessening of total exposure time. The primary responsibility for attempts to reduce noise, however, lies with the aircraft designers and engineers, the architects who design new facilities for Air Force bases, and those who develop maintenance procedures. The Medical Service has

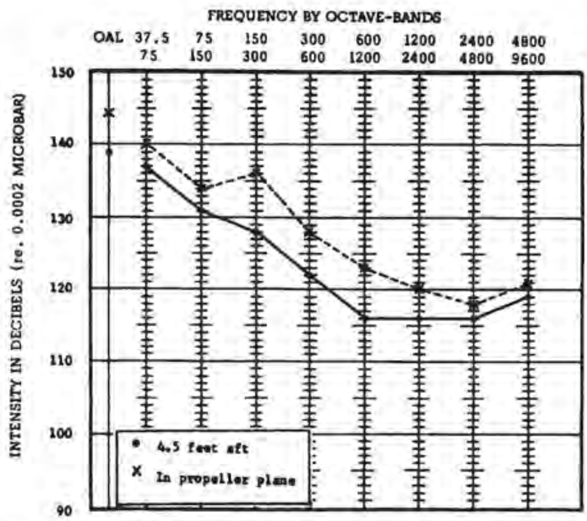


Figure 7–15. C–133A External Propeller Noise, 3140 HP, 80% of Normal Rated Power.

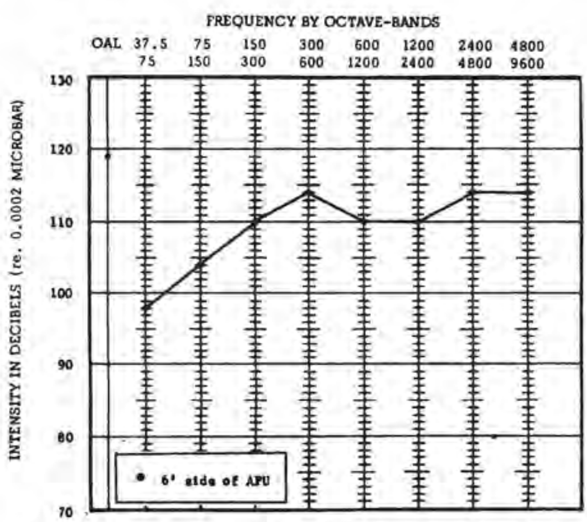


Figure 7–16. Ground Crew Exposures Near Side of C–133A Aircraft Auxiliary Power Unit.

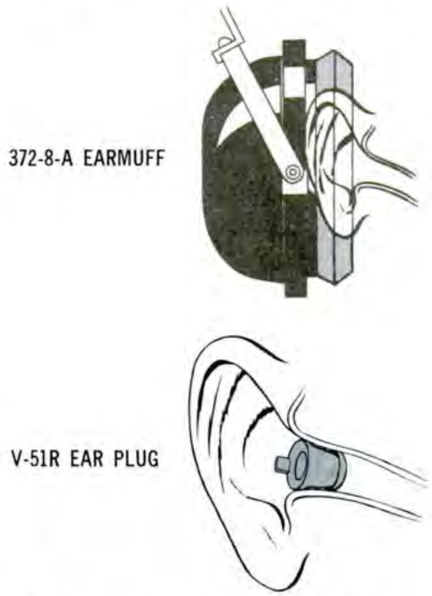


Figure 7–17. Air Force Standard Stock-Listed Items of Ear Protection.

responsibility for advising civil engineers regarding noise reduction and protection characteristics in new buildings and base designs. On the other hand, the Flight Surgeon is wholly responsbile for providing personal protective measures to persons who must work in high noise levels. Protective measures are discussed as follows:

Types of Protection

Ear defenders available are of two general types: those inserted into the ear canal (earplugs), and those worn over the ear (headsets, helmets, and earmuffs). The current Air Force issue earplug is molded in a standard design known as the V–51R. It is made of vinylite and comes in five sizes. Standard Air Force earmuffs may be one of several designs. Figure 7–17 shows the standard earplug and one version of earmuff. The muffs are also available with earphones and a noise-cancelling microphone mounted in a noise shield. These communication muffs are primarily for use by ground crew personnel during engine runup and checkout operations.

Standard aircraft headsets and cushions are not specifically designed for use as ear protectors, however, they provide some degree of noise attenuation. Such headsets provide good attenuation in the higher frequency ranges, but very little in the lower ranges. Therefore, the items expressly developed for hearing protection (the V–51R earplug and the various earmuffs) are always to be preferred when effective attenuation of noise is of paramount concern.

Protection Provided

All types of defenders block out or attenuate noise of high frequency more effectively than noise of low frequency. There is a fairly regular increase in efficiency of the defenders with rise in frequency. The V–51R may attenuate as much as 20 or 25 db in the low frequencies and 35 db or more in the high frequencies (see figure 7–18). The exact amount of protection afforded by a specific defender will vary among persons being governed principally by how good a fit is obtained. It will vary for any one person at different times, depending upon how carefully he has inserted the defender. Muffs now available to Air Force personnel are as effective as well-fitted earplugs. They provide a convenient means of increasing the attenuation of dangerously high noise levels when they are worn in addition to insert plugs.

There is a definite limitation on the degree of protection which can be afforded by defenders of the insert or headset type. This limitation is imposed by the fact that airborne sound, when it becomes sufficiently intense, initiates vibrations of the skull which, in turn, are carried to the cochlea through the bone; thus, they bypass the outer and middle ears. The threshold for such transmission is high compared to that for air conduction of sound, but it is well below the levels which are commonly encountered during aircraft operations. Although, theoretically, a perfect earplug might attenuate noise as much as 60 db, such a plug would not guarantee safety from hearing loss at noise levels of 140 db or higher since a very appreciable portion of the sound energy at these levels would reach the cochlea by bone.

Precautions in the Use of Personal Ear Protectors

For an insert-type earplug to be most effective, it must make an airtight seal of the

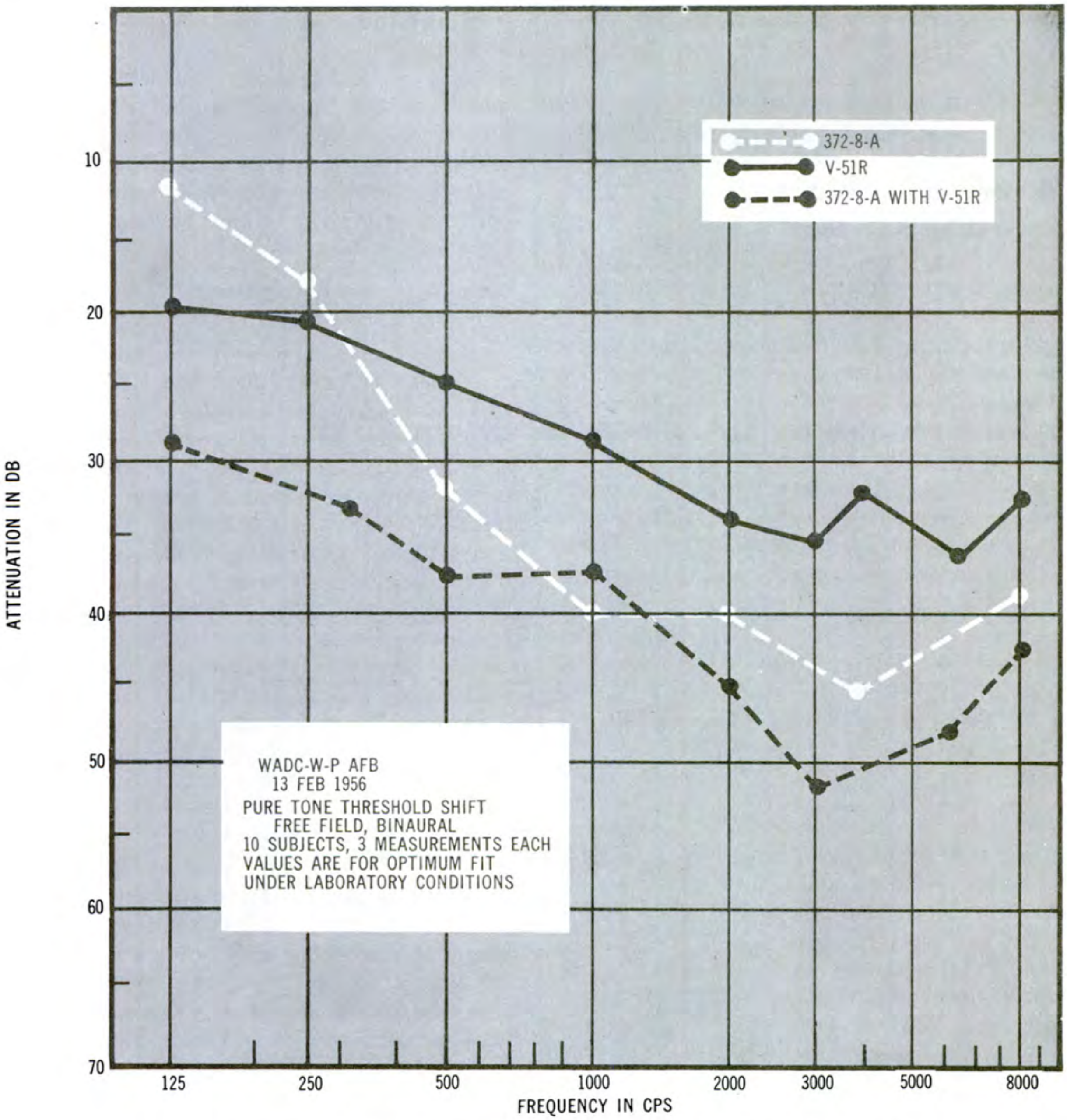


Figure 7–18. Attenuation Characteristics of Standard Ear Protection Devices.

external ear canal. The following factors should be remembered when earplugs are to be fitted and used:

a. The earplug must fit tightly if it is to offer the maximum allowable attenuation. People who are not accustomed to earplugs often complain that the properly fitted earplug is "too tight," but after wearing it routinely for about two weeks they find that it is comfortable. This is probably due to the fact that they have become accustomed to the feeling of tightness or pressure.

b. Personnel fitting earplugs should always fit each ear separately. In many instances, people have different-sized ear canals.

c. Earplugs should be kept clean and dry.

d. When earplugs become brittle, they should be replaced and a new fitting made. Matching the previous earplug size is not to be assumed as adequate.

Use of Defenders in Flight

Insert-earplugs are particularly effective under flight conditions. They serve to attenuate the ambient noise in the cockpit to a greater degree than that accomplished by the headset alone. They further act to improve the clarity of the radio signals. Defenders attenuate proportionately more of the static coming over the radio than they do of the speech signals. Therefore, they allow a signal which is less distorted and one which stands out better over the noise background. If desired, the volume control can be turned up to permit a louder signal.

There is an operational limitation, however, which makes it mandatory that any insert-defender other than dry cotton be used with caution under flight conditions, and that only dry cotton be worn under a close-fitting helmet. If a defender worn in the outer canal seals perfectly, there will be an airtight pocket in the canal between it and the tympanic membrane. On ascent, the air in this pocket will expand and tend to equalize with the ambient pressure by pushing the plug out a bit and escaping around it. If the wearer then tightens the seal of the defender, he will again have an airtight pocket. A negative pressure, however, will exist between the plug and the tympanum on descent. The plug will tend to be pushed in, and discomfort or true vascular damage to the soft tissue of the canal may result.

The term *aerotitis externa* is used to describe this condition. Experience has shown that such pathology occurs very rarely. Yet, flight personnel should be warned to watch for it, and to remove the defenders before or during descent if any discomfort is aroused. *Under no circumstances should imperforate ear defenders be worn under protective flight helmets and full or partial pressure helmets.*

In the past, it was recommended that a tiny perforation be made in the defender to allow for pressure equalization. Several commercial companies have manufactured plugs which embody a perforation or a valve. Nevertheless, dependence upon such defenders is not recommended as the effectiveness of the perforations or valves is voided by the entrance of even the tiniest speck of dirt or cerumen.

Use of Defenders During Ground Operations

Ear defenders should be made readily available to all persons whose duties carry them near or on the flightline. Included in this group are the crews assigned to particular aircraft; the alert crews who service transient aircraft; the men who carry on repair work in the hangar and remove and reinstall equipment in the aircraft while other maintenance is going on (radio and radar men among others); and the fuel truck and tow-tug drivers. Often overlooked in the distribution of defenders are the firemen and air policemen who, for hours at a time, are stationed as guards at various points on the flightline. Noise levels often exceed 100 db in and near the hangars. Other on-base areas—such as firing ranges, air-conditioning plants, and ground power, carpenter, and welding shops—should not be neglected.

The defenders should be worn by all men in the immediate vicinity of an operating aircraft, even though the engines are only idling. Men working both inside and outside the aircraft are included, and especially the men who maintain outside contact with the pilots or engineers by intercom. The defenders should be worn by all within a wide area when engines are run to higher than idle power levels. The specific distances within which defenders should be worn will vary with the type of aircraft and its position with respect to the individual. No aircraft (jet, propeller or helicopter) is excluded here.

As a general rule, both ear plugs and muffs or plugs and noise-excluding headsets should be provided when noise levels are in excess of 135 db, and especially when they exceed 140 db. The exposure duration and frequency of noise levels will affect these values. (See AFR 160-3.) Such intensities are found in work positions around the B-47, B-52, B-58 and the "Century Series" fighters, and especially near the tailpipe of any aircraft equipped with afterburners when the latter are in operation. Every effort should be made to minimize the duration of such exposures, and to allow an extended time period between such exposures for any one person.

Both flight and ground personnel who learn to wear ear defenders regularly find the annoyance formerly created by noise to be lessened or eliminated entirely. Speech is understood more easily. Temporary deafness, "fullness" of the ears, tinnitus, and diplacusis following exposures are minimized.

Men who once experienced excessive fatigue and irritability after working on or near jet engines all day, find themselves in relatively good physical and mental condition following such duties when they have protected their ears. Those who have suffered nausea, equilibrial disturbances and other unusual symptoms may not do so when defenders are worn.

A few persons will be found who, even with the best of current defenders, continue to experience ill effects from noise. The Flight Surgeon must be continually on the alert to screen out and reassign the exceptionally susceptible men.

Indoctrination on the Need for and Use of Defenders

Although the need for and the effectiveness of ear defenders had been recognized in scientific circles for many years, it was not until jet aircraft were in fairly widespread operation that the idea of ear protection was generally accepted by men working in excessive noise. There remain numerous entire groups and many people within other groups who are not aware nor convinced of the facts in the preceding pages.

Various reasons for this situation are evident. The most pronounced is ignorance on the part of supervisors and workers alike, of the need for and value of defenders. Inadequate knowledge of airmen on how to handle defenders, poor fitting of those who have them, and unreliable supply channels also are contributing factors.

The Flight Surgeon must assess the situation on his base and initiate a vigorous program of indoctrination designed to correct whatever phases may be faulty. His program will succeed more rapidly if he concentrates his initial efforts on the older and generally respected men. When the line chiefs and crew chiefs are convinced, it is an easy matter to persuade others to follow suit, including both airmen and officers. Many will then ask for defenders.

Fitting ear defenders in the noise environment is an excellent method of demonstrating both the decreased annoyance and the adequacy of speech perception while wearing the defenders.

Approximately 98% of ears can be fitted adequately with one of the five sizes of V-51R design earplug. It is essential that each ear of a person be fitted separately as the two often require different sizes. There are a few people whose outer ear canals are either too small or too large for this type of earplug; a few others have peculiar configurations of the outer ear which defy

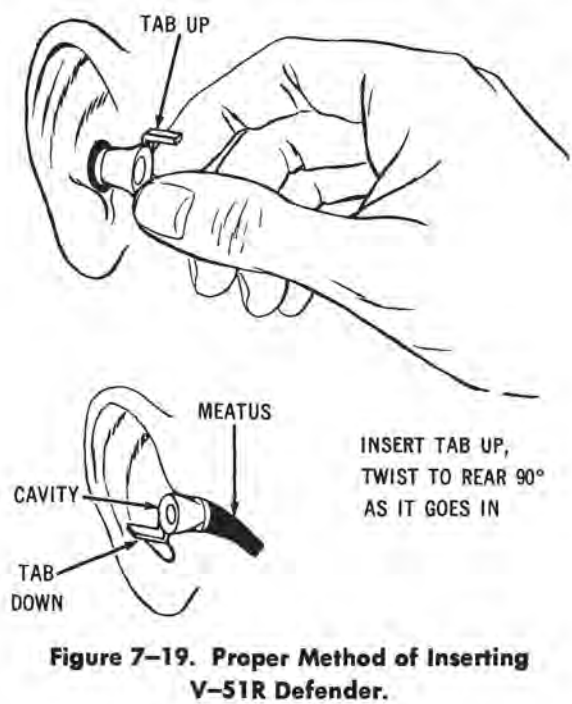


Figure 7-19. Proper Method of Inserting V-51R Defender.

proper fit. Other procurable plugs should be tried for such persons. Men suffering from external otitis can use only dry cotton and headsets or muffs until the infection is cured.

Figure 7–19 shows the proper method of inserting a V–51R defender. The pinna is drawn upward, outward, and forward with one hand, as it is prior to the introduction of a speculum. The tab of the defender is grasped between the thumb and forefinger of the opposite hand in such a manner that the tip of the forefinger covers the central cavity of the plug. The plug is then introduced into the external meatus and moved inward with a twisting motion until the outer rim rests snugly against the auricle. The tab is directed superiorly as insertion begins but is rotated 90° posteriorly during the procedure. When the plug is properly seated, the tab should be positioned to the rear of the head.

As other and more effective defenders are developed and made available, the Flight Surgeon must make certain that those responsible for these fittings are trained in the proper use of each style. With experience, each fitter will learn to recognize when a proper fit is achieved. He will often find that a defender which is actually too small will be judged as too large by the wearer. A small plug enters sufficiently far to come in contact with the more sensitive portion of the canal and, therefore, is perceived as "too big." A proper fit is one in which the plug is large enough to seal the canal thoroughly, yet not so large as to create true discomfort or pain. The person soon will become accustomed to the feel of the defender, even though he may not like it at first.

To insure effective utilization of the defenders, it is essential that each man be shown how to insert the plugs, how to remove them, and how to care for them. Mechanics' hands are frequently covered with grease, fuel, and other contaminating agents. Further, many men's fingers are large, blunt, and have only very short nails. Also, the external meatus is so far forward under the tragus in some persons as to make proper seating and removal of defenders particularly difficult. In many of the latter cases, the insertion can be aided by having the man reach over his head with the opposite hand and pull the pinna up, forward, and out, as is done by the fitter. Each man must practice in order to develop his own technique of handling the tiny plugs so that he can manage insertion and removal quickly.

REFERENCES

The reader should insure the currency of listed references.

Ades, Harlow W., *et al*, *Nonauditory Effects of High Intensity Sound Stimulation on Deaf Human Subjects*. Journal of Aviation Medicine. 29:6, pages 454–467 (1958).

Ades, Harlow W., *et al*, *Threshold of Aural Pain to High Intensity Sound*. Aerospace Medicine. 30:9, pages 678–684 (1959).

Barron, C., *Audiometric Studies of Flight Line Mechanics*. Journal of Aviation Medicine. 28:295–302 (1957).

Davis, H., *Effects of High Intensity Noise on Naval Personnel*. Armed Forces Medical Journal. July 1958.

Doerfler, Leo G., *How We Hear and How Noise Affects Our Hearing*. National Safety News. July 1956.

Glorig, A., *Current Research in Industrial Noise*. Noise Control. 5:1, pages 32–35 (Jan. 1959).

Glorig, A., *Noise and Your Ear*. Grune & Stratton. New York, 1958.

Glorig, A., *et al*, *Hearing Loss in Industry*. Laryngoscope 68:3, pages 447–465. March 1958.

Guide for Conservation of Hearing. Subcommittee on Noise in Industry of the Committee on Conservation of Hearing, 111 North Bonnie Brae St., Los Angeles, California (1957).

Hirsh, Ira J., *The Measurement of Hearing*. McGraw Hill, Incorporated. New York, (1952).

Kraus, Ralph N., *The Air Force Hearing Conservation Program*. School of Aviation Medicine, USAF, Aeromedical Review 3–58, September 1957.

Kraus, Ralph N., *An Evaluation of Patients Suspected of Having Noise-Induced Hearing Loss.* School of Aviation Medicine, USAF, Aeromedical Review 4-59, June 1959.

Medical Aspects of the Noise Problem, SAC Technical Pamphlet 160-1. Hq Strategic Air Command.

Miller, Laymond N., *Controlling Industrial Noise Hazardous.* Safety Standards. July-August 1957.

Newman, E. B., *Psycho-physical Effects of Noise.* Noise Control. 1:4, pages 16–21 (1955).

Noise Characteristics of Air Force Turbojet Aircraft. Wright Air Development Center (WADC) Technical Note 56–280; Armed Services Technical Information Agency (ASTIA) Document No. AD 110680. Dec. 1956.

Noise Produced by Aircraft During Ground Runup Operations. WADC Technical Note 65–60; ASTIA Document No. AD 130763, Wright Air Development Center. June 1957.

O'Connell, Max H., *Hearing Acuity of Air Force Recruits.* School of Aviation Medicine, USAF, Report No. 58–70, April 1958.

O'Connell, Max H., *Aircraft Noise.* School of Aerospace Medicine, USAF, Aeromedical Review 3–60, June 1960.

Rosenblith, W. A., *et al, The Relations of Hearing Loss to Noise Exposure.* American Standards Association, Inc., New York. (1954).

Rosenblith, W. A., *et al, Handbook of Acoustic Noise Control, Volume II, Noise and Man.* WADC Technical Report No. 52–204. 1953.

Thiessen G. J. and Shaw, E. A., *Ear Defenders for Noise Protection.* Journal of Aviation Medicine. 29:11, pages 810–814. (1958).

von Gierke, H. E. and Pietrasanta, *Acoustical Criteria for Work Spaces, Living Quarters, and Other Areas on Air Bases.* WADC Technical Note 57–248, Wright Air Development Center, November 1957.

Waldron, Daryle L., *A Preliminary Study of the Efficiency of Limited Frequency Monitoring Audiometry in the Air Force Hearing Conservation Program.* School of Aviation Medicine, USAF, Report No. 59–89, August 1959.

Waldron, Daryle L., *A Study of the Reference and 90-Day Audiograms of a Group of Air Force Aircraft and Engine Maintenance Men.* School of Aviation Medicine, USAF, Report No. 59-96, Oct 1959.

AFM 86–5, *Land Use Planning With Respect to Aircraft Noise.*

AFR 160–3, *Hazardous Noise Exposure.*

AIHA Industrial Noise Manual, 2d Edition, Chapters 6 to 10, American Industrial Hygiene Assoc. (1966).

TF 1–8193, "Meet Mr. Noise," September 1962.

Chapter 8

SPECIAL PROBLEMS OF THE EYE

The problem of protecting the flier's eyes from blast, light, and trauma, always present in the past, has become more difficult with the advent of supersonic aircraft, high-altitude flight, and the use of nuclear war-heads in the weapon systems. Physical factors, such as aircraft speeds exceeding that of sound, exceedingly high altitudes reversing the former environment of fliers, very low barometric pressures, cosmic radiation, and the flash from nuclear devices, are some of the problems facing the airman of today and tomorrow.

AFR 160-112 contains specific guidance concerning the Occupational Vision Program. This program basically covers the subjects of eye protection to personnel employed in hazardous environments, vision testing associated with placement of personnel, and the prescribing of safety glasses.

GENERAL EFFECTS OF ALTITUDE

Visual difficulties of the human organism at high altitudes are due to hypoxia, decompression, glare, and empty visual field.

Visual Effects of Hypoxia

The hypoxia which affects the flier as he ascends may cause several changes in his ability to see. These visual disturbances, and the ophthalmoscopically visible changes in the blood vessels which accompany them, are described in this chapter.

The range from sea level to 10,000 feet is known as the *indifferent zone,* because ordinary daytime vision is unaffected up to 10,000 feet. There is, however, a slight impairment of night vision, a fact which makes it imperative for night combat fliers to use oxygen equipment from the ground up.

The range from 10,000 to 16,000 feet is called the *zone of adaptation,* because even though visual functions are impaired, the flier is able to overcome the impairment sufficiently to carry on his duties. In this zone, the following changes occur, becoming progressively greater with increasing altitude: the retinal vessels become dark and cyanotic; the retinal arterioles increase 10 to 20% in diameter; retinal blood volume increases up to four times; the retinal arteriolar pressure increases along with systemic blood pressure; the intraocular pressure increases somewhat with the arteriolar pressure; the pupil constricts; there is a loss (at 16,000 feet) of 40% in night vision ability; accommodation and convergence powers decrease; the ability to overcome heterophorias diminishes.

All these changes are returned to normal by either administration of oxygen or return to ground level. Up to 16,000 feet, these effects remain *latent,* in the sense that physiologic compensatory reactions enable the flier to continue his task, unless this altitude is maintained for long flights without oxygen.

The region from 16,000 to 25,000 feet is called the *zone of inadequate compensation,* because one or several of the preceding changes becomes severe enough to produce visual difficulties which do interfere with maintenance of job proficiency. Visual reaction time is slowed; motor response to visual stimuli is sluggish; mental processes are all slowed; heterophorias are no longer compensated by fusion, and become heterotropias with resulting double vision; accommodation is weakened and convergence lost so that instruments are both blurred and double.

Dilatation of retinal vessels, with the accompanying pressure changes, continues to increase until circulatory collapse intervenes. Visual acuity is impaired by diplopia, loss of accommodation, and general retinal and cerebral malfunction; night vision is seriously impaired. All these changes are reversed by use of oxygen or return to sea level.

Above 25,000 feet is the *zone of decompensation*, or zone of lethal altitude. In this zone circulatory collapse occurs, the flier loses both vision and consciousness, and may suffer permanent damage to his retina and brain as a result of death of neurones from severe hypoxia and lack of circulation.

Effects of Acceleration on the Eyes

The pilot's vision while flying may be affected by radial and rectilinear accelerations. These forces have different physiological effects depending on the posture of the pilot in the aircraft. When centrifugal force is increased in the head-to-seat direction, a considerable stasis of blood in the splanchnic viscera and lower limbs results, progressively dilating the venous and arterial system. The quantity of blood returning to the heart is diminished as a result of this stasis. The heart continues to beat; but the diminution of the volume of the systolic blood wave reduces the cardiac output and lowers the arterial tension, which may drop to zero at the carotids if acceleration is greatly increased.

When the carotid pressure is diminished by centrifugal force, a point is reached where it is impossible for retinal arterial pressure to exceed intraocular pressure. At this point, visual function is impaired. Effects vary on individuals, but in general, one may say that pilots will grey out at 4 Gs, black out at 5 Gs, and lose consciousness at 6 Gs, if they are unprotected.

Three methods have thus far been suggested for protection from head-to-seat forces. The first is a reclining seat which automatically tilts the pilot into a supine position when centrifugal forces exceed certain intensities. This, however, is impractical in combat. The second method is by enclosing the lower part of the body in a G-suit. A third method is placing the pilot in the prone position in which he can tolerate about 12 Gs before breathing becomes impossible.

Negative G forces, if prolonged, result in congestion of all vessels of the upper part of the body. Congestion of the face and violent headache may follow. A so-called "red-out" may occur. The actual cause of this phenomenon is unknown. It may be due to congestion of the orbital contents, or to cerebral and/or retinal congestion.

Effect of Glare at High Altitudes

The pilot who flies at altitudes in excess of 40,000 feet encounters the problem of glare from the cloud layer below his aircraft. The human facial contour is not formed to protect the eyes from glare coming from below the eyes. This situation causes the flier to develop a haziness of vision from the glare below him. One investigator has indicated that the cause of this subjective haze is probably the persistence of a positive afterimage of the bright cloud floor.

Other causes of this haziness of vision have been suggested and investigated. These include fluorescence of the crystalline lens caused by greater intensity of ultraviolet light at high altitude and intraocular scatter of light.

The cause of this subjective haze has not been clearly established. Possible solutions to the problem may be through use of the following type filters. These filters would, of necessity, vary in design due to the various aircraft configurations affecting visibility.

a. Maximum absorption in central portion with increasing transmission superiorly and inferiorly.

b. Maximum absorption in superior portion with a gradual increase in transmission towards the center and inferior portion.

c. A self-attenuating variable density filter.

This would be the ideal type of protection in that the transmission of light would be dependent upon the intensity of light incident upon the filter, constant transmission resulting at all times.

The glare from below and the sides in combination with the lack of light scatter in the environment at high altitudes may cause a relative shadow on the instrument panel. Since the external environment is bright and a relatively small amount of light diffuses into the cockpit, the instrument panel may appear to be in a shadow when the pilot turns his attention from outside the aircraft to his panel. The solution to this problem is the use of white light in the instrument panel. The brightness of the panel can then be equalized with environmental lighting by a rheostat controlling panel light intensity.

Effect of Space Myopia (Empty Visual Field)

At high altitudes, pilots may develop "physiological myopia" due to the normal ciliary muscle tone when the eye is at rest. At these altitudes, one may not have a distant object on which to fixate. In such an empty visual field, a reflex accommodation occurs, creating from 0.50 to 2.00 diopters of relative myopia. Theoretically, under this condition, an emmetropic individual would be incapable of detecting a target at his normal "far point."

For example, a pilot with normal visual acuity of 20/20 is able to discern an aircraft having a fuselage diameter of 7 feet at a distance of 4.5 miles. The same individual accommodating 0.50 diopter, would then be able to detect the same aircraft at a distance of only 3 miles. Another possible solution would be to use pilots who are slightly hyperopic.

Sunlight and its Effect on the Eyes

Light is part of the energy spectrum. The entire spectrum extends from the extremely short cosmic rays with wavelengths on the order of 10^{-12} centimeters to the long radio waves, several miles in length. Visible light consists of a small portion of the spectrum, from 380 millimicrons (violet) to about 760 millimicrons (red). A millimicron is a millionth of a millimeter. The neighboring portions of the visible spectrum, although not visible, have their effects on the eye and are therefore of interest.

Wavelengths of 360 millimicrons and shorter, down to 200 millimicrons are known as abiotic rays. Exposure of the eyes to this portion of the electromagnetic energy spectrum produces ocular tissue damage, the severity dependent upon intensity and time of exposure. Wavelengths longer than 760 millimicrons to the microwaves at about 1 mm are the infrared or heat rays. These rays, too, may cause ocular tissue damage depending upon intensity and exposure time. The infrared rays may affect all ocular tissues, whereas the ultraviolet have their effect chiefly upon the conjunctiva and cornea.

The light intensity in extraterrestrial space above 100,000 feet is approximately 13,600 foot-candles. At 10,000 feet on a clear day, it is about 12,000 foot-candles, and at sea level on a clear day, it is about 10,000 foot-candles. It is obvious that something in the atmosphere is absorbing light. Water vapor, dust particles, and air absorb light. In addition to absorbing light, water vapor also scatters light. This accounts for the unexpected sunburn on overcast days.

In addition, certain selective absorptions occur. The ultraviolet light shorter than 200 millimicrons is absorbed by dissociated oxygen as high as 400,000 feet. Below this level, these wavelengths are of no consequence. The ultraviolet light 200 to 300 millimicrons in wavelength is absorbed by the ozone layers in the atmosphere. This is very fortunate because the wavelengths from 200 to 300 millimicrons are the most damaging to the eye.

It is these wavelengths that produce the actinic conjunctivitis which welders receive when they fail to wear protective hoods. These wavelengths from 200 to 300 millimicrons are no problem until an altitude of about 125,000 feet is reached. This is about the height of the second ozone layer. Above this altitude, these ultraviolet wavelengths between 200 and 300 millimicrons will require consideration.

The rays of particular concern, therefore, are from 300 to 2,100 millimicrons in wavelength with an intensity varying between

10,000 foot-candles at ground level to about 13,000 foot-candles at presently attainable altitude.

Brightness of the Field of View

The amount of light reflected back to the eye determines the brightness of the individual's field of view. Snow, for example, may reflect back to the eye 85 to 90% of the light falling on it. White sand, coral, and white clouds may reflect as much as 75 to 80% of light. Grass and forests may reflect as little as 10% of light. The apparent "coolness" of green fields probably depends as much upon the fact that they reflect low percentages of light as it does upon any specific psychological effect of the color.

Insofar as the feeling of brightness in sunlight is concerned, then, there are two factors: the amount of light falling on a surface, and the amount of light reflected by the surface.

The Effect of Light on the Eye

There are certain specific effects which light may produce in the eye. First, consider ultraviolet radiation which produces its harmful effects externally. The short rays which do the damage are absorbed by the outer one-tenth of a millimeter of the eyeball. Hence, the effect of these rays is limited to this area of absorption.

Ultraviolet light produces a painful swelling accompanied by extreme sensitivity to light—photophthalmia, or so-called snow blindness—that one experiences in the Arctic. It is only produced after prolonged exposure to sunlight of high intensity, such as that reflected into the eyes by a snow field, the surface of water, or a bright desert. Ultraviolet burns do not produce permanent damage to the eye, although pain is severe.

Both infrared and visible light contain a great deal of energy. If an individual looks directly at the sun with inadequate eye protection (all so-called sunglasses are inadequate for this purpose), the lens system of the eye will concentrate this energy on the retina like a burning glass and will produce an actual burn of the retina. This happens so frequently during observation of an eclipse of the sun that it is called "eclipse blindness." It is a permanent eye injury and clinically is manifested by a macular scar. There will be present a central scotoma as demonstrated on the tangent screen. Vision may be 20/70 or less.

Infrared is also reputed to cause chronic redness of the eyes, chronic conjunctivitis, and pterygium. Its role in these eye conditions is still not completely determined.

Effects of Sunglasses and Other Ophthalmic Filters on Light

Plain crown glass as used in spectacles will eliminate most of the ultraviolet. Thus, if an individual wears spectacles which have large enough lenses to prevent ultraviolet light from entering his eyes around their periphery, he is protected to a great extent against snow blindness. Glare may bother him but he will not develop photophthalmia. Plastic lenses, if clear, transmit ultraviolet unless made from one of the new special plastics. Current aircraft plastic canopies do transmit ultraviolet. In general, dark-tinted plastics do not transmit ultraviolet, but there are exceptions.

If sunglasses with glass lenses are being considered, then one must be chiefly concerned with what these lenses do to visible and infrared light. All these wavelengths pass through crown glass with only about an 8% reduction. (Magnesium fluoride coated lenses absorb only 4% of light and allow 96% to pass through.)

Sunglass lenses of all types filter light. There are four types of sunglass lenses in common use:

Colored filters	Reflecting filters
Neutral filters	Polarizing filters

They all have in common the fact that only a certain percentage of the total amount of light gets through to the eye. They produce this effect differently. The colored, neutral, and polarizing filters achieve this effect by absorbing some of the light and allowing the rest to pass.

Colored Filters. The reason that a green sunglass looks green is that it absorbs a higher percentage of the other colors than it does of the green. It allows the green to pass through. The same is true of other colored sunglasses. They permit different amounts of light of different wavelengths to pass. Yellow or amber sunglasses, for example, absorb all the blue light and most of the green and allow only red, orange, yellow, and a little of the green to reach the eye.

Neutral Filters. On the other hand, neutral filters absorb approximately equal amounts of all wavelengths of light—as much of the red as of the green, the blue, or any other color. For this reason they appear gray. (However, all gray-appearing filters are not necessarily neutral.) They darken a scene without changing its colors.

Reflecting Filters. Reflecting filters allow a certain percentage of light to pass to the eye and reflect the remainder back in the general direction of its source. They act very much like partially silvered mirrors, and when worn, they resemble small mirrors. The silver-colored coating on the upper part of certain "graded density lenses" is such a filter. It is usually a thin coat a mixture of chrome and nickel. As a rule, these reflecting filters are nearly neutral in that they reflect an approximately equal percentage of all wavelengths.

Polarizing Filters. Polarizing filters transmit only light that is vibrating in a certain direction. They absorb light vibrating in other directions. They are not neutral in that they pass more light of certain wavelengths than of others. Polarizing filters pass about 30% of light unless they are polarized in one particular plane. For this reason, they require combination with other types of filters to be effective as a general-purpose sunglass.

They have an additional disadvantage in that the polarizing film is made up of very minute crystals. This film is quite delicate and must usually be placed between two layers of glass, to protect it. It also produces a certain amount of peripheral distortion and is subject to deterioration after a time. In addition, the lamination required makes it expensive to produce curved lenses or those in which corrections can be ground.

Filters used for sunglass purposes have their density described in terms of the amount of light they transmit. Thus, a 15% filter will allow 15% of the visible light falling on it to pass through. If it is a neutral filter, this will be 15% of each wavelength of visible light. If it is a colored filter, it may be only 1 or 2% of one wavelength and as much as 30 or even 40% of another wavelength.

It is emphasized that colored lenses do not "add yellow" or "add green" to the light. They cannot add anything. They only make things appear to be certain colors because they subtract other wavelengths of light by absorption or reflection.

Most ophthalmic filters transmit rather large percentages of infrared radiation, especially the near infrared source. Manufacturers of sunglass lenses are prone to show the fine infrared absorption of their lenses around 4,000 millimicrons. If it is recalled that sunlight has almost no infrared longer than 2,100 millimicrons, it can be readily seen that this characteristic has no significance for wear in sunlight. There are a few sunglass lenses, however, which do have a low infrared transmission.

Reduction in the total amount of light may aid one's ability to see when the total brightness is so high that one cannot adapt to it by the normal eye mechanisms. If retinal adaptation, small pupil, and partially closed lids do not sufficiently reduce the amount of light entering the eye, the person will be unable to see well. This may happen when flying just above a dense sunlit overcast or flying over snow or over water into the sun. The use of a filter lens will reduce the over-all brightness to a level that can be tolerated and will allow the individual to see properly.

Glare. It is frequently stated that filter lenses will reduce glare. This statement is usually scientifically incorrect. Glare is caused by a difference in brightness between various parts of the visual field. The eye is dazzled by a lighter object because it is adapted for the darker portion of the field. Glare is then present. Putting on the usual filter lens reduces the brightness of all objects by the same amount, so that it does not change the ratio between the brightest and the darkest areas. Therefore, glare is still present.

These filters can reduce glare when the bright area consists of polarized light, such as the sun path on paving, snow, water, or similar surfaces, and the filter used is a polarizing one which will, then, selectively reduce this brighter area more than its background. Polarizing lenses have certain disadvantages previously mentioned which limit their use. These disadvantages will be discussed below. Polarizing lenses are further limited in their usefulness due to the small portion of polarized light in the daily environment. In general, then, it can be said that sunglass lenses do not reduce glare.

Color Perception. It is quite obvious that colored sunglass lenses will distort color perception to varying degrees. The degree of distortion will depend upon the amount of the various wavelengths absorbed by the lenses. Carefully designed experiments will show some degree of color perception error induced by any colored lens. Only with a true neutral filter is color vision entirely normal.

Visual Acuity. The ability to distinguish small objects at long distances is essential for the flier. The amount of light during the day is in excess of that required for maximum acuity. For this reason, it can be reduced considerably by a filter lens without reducing ability to see distinctly. A lens of about 10 to 15% transmission has been shown to be the most useful. (This is true, provided that the lens is somewhere near a neutral lens.)

A slightly darker lens could be tolerated under conditions of extreme brightness, but the lens of 10 to 15% transmission is adequate. On sunlit days, this density will not reduce acuity. The lenses should be removed if the illumination falls below bright sunlight, or acuity will be decreased. This is particularly true at dusk and at dawn.

Claims have been made that certain lenses increase acuity—especially the yellow or amber lenses. This statement is usually based on the way light is scattered by haze or fog. It is known that the shorter wavelengths (blue and blue-green) are scattered more by haze and fog than the longer wavelengths (red, orange and yellow). On theoretical grounds, then, the elimination of the short wavelengths by a filter should increase the sharpness of an image. This would seem to be confirmed by the use of yellow filters in photographing distant scenes. Such filters absorb the short wavelengths and allow the long ones to pass. They do give sharper pictures of distant scenes.

Such yellow filters, when worn, give a subjective sensation of increased brightness (a false impression because the lens subtracts light; it does not add it). These yellow filters also give a subjective sensation of sharpening the image. However, all carefully controlled research experiments conducted to date fail to show an increased ability to see in haze and fog by using yellow filters.

The difference between the effect on the eye and the effect on film is readily explained by the relative sensitivity to blue light of the photographic film on one hand and the retina of the eye on the other. Photographic film is extremely sensitive to blue light. Scattering of blue light, therefore, gives a marked haziness to pictures. On the other hand the human eye has a very low sensitivity to blue light, so the scattering has very little effect on ability to see in haze or fog. We have not yet developed any sort of ophthalmic filter which will appreciably increase the ability of the eye to see in haze or fog.

Underwater Search. Certain types of sunglasses have been advocated from time to time for search of submerged objects, such as submarines. Polarizing lenses have been suggested because of their absorption of polarized light from the water surface. Extensive experimental tests have failed to demonstrate any superiority. This is probably true because, at the time polarized light is reflected from the surface of the water, it is also reflected from the curved surface of the submerged object.

The polarizing filter absorbs both sets of light rays equally so there is no advantage. When the line of sight is from other directions in which light is not polarized, the polarizing filter again has no advantage. For these reasons, polarizing sunglasses are only useful to reduce over-all brightness to a comfortable seeing level without any specific improvement in ability to locate submerged objects.

Selection of a Sunglass for Air Force Use

Selection of the best sunglass lenses for Air Force use must take the above factors into consideration. It has been determined that a lens with 15% transmission is most suitable for the level of brightness encountered in flying.

The elimination of electromagnetic radiation, which one cannot see and which may be damaging to the eye under certain conditions, presents no problem so far as ultraviolet is concerned. Glass lenses eliminate most of the abiotic wavelengths below 300 millimicrons. However, fluorescence of the crystalline lens may present a problem at high altitudes when lenses are used which transmit light in the region of 360 millimicrons.

The infrared rays are eliminated significantly better by the presently available neutral lens than by any of the colored lenses or the reflecting lenses. The ability to recognize colors without any impairment occurs only with neutral lenses—either absorbing or reflecting types. (Colored lenses distort colors.)

Visual acuity is as good through the neutral lenses as any of the colored type yet developed. It is not better, but is just as good. No lens has yet been shown to increase ability to penetrate haze or fog.

Careful review of these points shows the superiority of the neutral over the colored or polarizing lens. The neutral absorbing lens is superior to the neutral reflecting lens because of the infrared transmission of the reflecting lens and because the reflecting coat is rather susceptible to damage.

Use of Goggles

Goggles have lost their importance as protection against wind blast, oil droplets, flash fire, and so forth. Fighter pilots now use visors attached to the helmet. This visor, which can easily be pulled down or pushed up with one hand, protects the eyes against particles, oil spray, and the like. In addition, the visor protects the eyes against wind blast in bailouts at speeds less than supersonic. Speeds in excess of 500 knots cause the visor to be torn off by the wind blast.

Special goggles are valuable today as protection against flashblindness and chorioretinal burns in the case of nuclear detonations. A pilot who will be exposed to nuclear detonations, whether from his own or an enemy's nuclear devices, needs protection against the possible eye effects resulting from the intense light and thermal energy produced by atomic fireballs in order to have the best possible chance for successfully completing his mission. Several research programs have been instituted, to provide the answer to this problem.

One approach has been a goggle containing an electromechanical shutter. The eye piece consists of movable glass plates with series of alternately opaque and transparent lines. With the shutter open, the transparent lines are superimposed over one another, and since the opaque lines are narrower than the pupillary aperture, the pilot can see without any blind spot in his visual field.

When the flash detector senses the presence of unusual illumination above a preset level, it produces a signal which discharges one of four dimple motors. The dimple motor drives a wedge which moves one of each set of grids laterally. This causes an opaque line to cover a transparent line and an opaque lens results.

Another protective device which, if successfully developed, may be incorporated in a goggle, is a "variable density filter." This filter will contain a photochromic system (dye) which is sensitive to a specific amount of illumination. With a rise in the incident illumination to the specified light intensity, the filter immediately becomes opaque. This can be a reversible reaction, with clearing of the filter under reduced illumination. Research in the protection of eyes against nuclear flashes will continue into the future.

NUCLEAR DEVICES

The detonation of atomic bombs over Hiroshima and Nagasaki in 1945 marked the beginning of atomic warfare. Nuclear weapon development since that time has resulted in devices that are many times more devastating than the nominal 20 KT bomb. Explosion of such devices results in damage to the human body by concussion (blast), radiation, heat, and light. The concussion and radiation effects are limited to finite distances from the center of burst; these can be predicted from the yield and location of the detonation relative to the earth's surface. The radiant energy released at detonation of a nuclear bomb in the form of infrared and visible light causes damage to the human body at finite distances.

The eye is more susceptible to injury at far greater distances than other organs or tissues of the body. An eye, having a pupil of a given size, exposed to a nuclear detonation at a given distance, will result in a certain amount of energy distributed over the image area on the retina. If the distance from detonation is now doubled, the amount of energy passing through the same size pupil will be one fourth as great; the image area will also be one fourth as large. Therefore, the energy per unit area will remain constant irrespective of the distance, except for the attenuations due to the atmosphere and ocular media.

The potential danger of flashblindness and chorioretinal burns resulting from viewing atomic fireballs has now become of great concern to aircrew members, and has thus created new problems for the Flight Surgeon.

The chorioretinal burns that result from exposure to nuclear weapon detonations vary in size and severity depending upon distance from the center of burst, the more severe burns being sustained at positions closer to point of detonation. Persons exposed to atomic flash beyond the point where retinal burns occur may, nevertheless, be subject to flashblindness of several minutes' duration. Although this is of a temporary nature, it could result in inability to complete mission or actual loss of the aircraft.

Permanent loss in visual acuity and central field would result from a chorioretinal burn in the macular or perimacular area. A burn in the mid periphery would result in either a localized scotoma if the burn were minimal, or in a segmental field defect if the burn were severe. Suggestions have been proposed to protect the eyes from the effects of atomic flash. These include the use of shades, blinds, or the covering of one or both eyes. These may be of value in offensive operations, but, for obvious reasons, would be valueless in defensive tactics.

Adequate protection of the eyes from atomic flash would appear to be the only method of preventing flashblindness and chorioretinal burns. Research in this area has been devoted to the development of filters and shutters that would absorb or occlude the infrared and visible light released by atomic fireballs. This is to prevent flashblindness and retinal burns, and yet provide adequate visibility immediately before and after detonation.

Investigation is now under way, therefore, to develop a self-attenuating variable density filter which would transmit a constant amount of visible radiation, regardless of the intensity incident to the filter. Success in this area would provide a method for protection of the flier's eye from flashblindness and retinal burns associated with the detonation of nuclear weapons.

VISUAL PROBLEMS OF SUPERSONIC SPEED

It is evident that speeds of 3,000 mph will be commonplace in the future. Obviously, many problems will arise when pilots are subjected to such speeds.* Among these problems will be the visual difficulties encountered. Airflow, vibration, acceleration, temperature, and lag in human visual perception time will all be factors. First, however, it is necessary to discuss the physical conditions which exist at these speeds before considering the visual problems.

At sea level, the speed of sound is approximately 760 mph—varying with density of air, temperature, and other conditions. As the altitude varies so does the speed of sound. However, at any altitude, speed of sound is

* Text and illustrations adapted from Byrnes, Victor A., *Visual Problems of Supersonic Speed*, American Journal of Ophthalmology 34:2 (Feb 51). Used by permission. Copyright 1951.

called Mach 1—Mach derives its name from an Austrian physicist. At ground level Mach 1 is approximately 760 mph. At 40,000 ft, Mach 1 is roughly 660 mph. Speed ranges are subdivided as follows:

Subsonic	Up to Mach 0.8
Transonic	Mach 0.8 to 1.3
Supersonic	Mach 1.3 to 5.0
Hypersonic	Over Mach 5.0

The same characteristic which regulates the speed of sound produces the compressibility phenomenon. Below sonic speeds, air particles are able to get out of the way of a moving body. Above Mach 1, air particles begin to pile up in front of it. As these particles of air bump against each other, they produce compression in the air. This is the phenomenon that enables sound to be transmitted. A wave front is built up before bodies moving faster than Mach 1. This wave front lying rather far ahead of the moving body is not very dense. The wave forms a more acute angle over the nose of the body as speed increases and it becomes denser. The nose of the plane is never able to pierce this compression wave (see figure 8–3).

In each of the speed ranges, the air behaves differently. For instance, air passing through a venturi tube at subsonic speeds has increased velocity but decreased pressure at the constriction in the tube. At supersonic speeds there is increased pressure as well as increased velocity at the constriction. Air flowing over the wing surfaces behaves differently in each of the different speed ranges. There is considerable buffeting in the transonic range because of the mixture of the two types of airflow. Going through this speed range of mixed airflows is called "passing through the sonic barrier." The present century-series aircraft are not affected by this buffeting because of their design and great speed in passing through the sonic barrier (figure 8–4).

Effect of Slanting Optical Surfaces

To permit supersonic flight, the aircraft must be free from projections, and optical surfaces must be slanted to produce the least possible drag. It has been found that a wind-

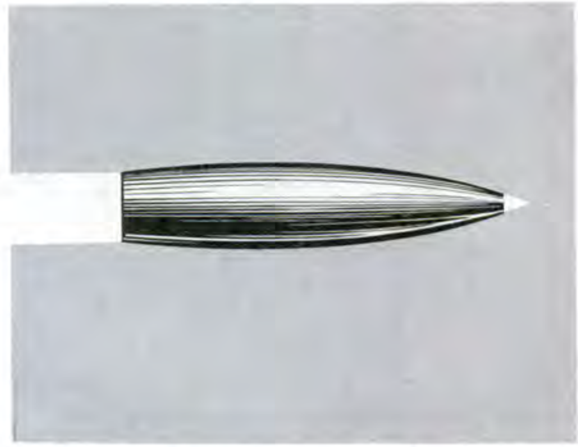


Figure 8–1. (Byrnes) Projectile Moving at a Speed of Mach 0.92 (700 MPH).

shield of bulletproof plate glass with nesa coating can be slanted to a 70° angle without producing measurable change in visual acuity or depth perception. No sizeable distortion occurs and it produces less than 3 minutes of deviation. However, the type of media used in the canopy will determine the angle at which the windshield can be slanted. There is a simple displacement of images produced by slanting surfaces in which emergent rays are parallel to incident rays. This, however, is not important.

Visual Effects Produced by Shock Waves

The air in shock waves is optically denser than normal air, producing a deviation of light rays which apparently displaces objects from their true position. This phenomenon varies with the speed between Mach 1 and Mach 4 and is entirely absent below Mach 1. The flow of air in the compression wave will obviously not be absolutely homogeneous and will probably produce mild rippling effects such as one sees in heat waves (figure 8–5).

Vibration

While the effect of vibration at supersonic speed has been a popular subject in the press, no vibrations of intensities great enough to harm human eyes have been produced by jets or rocket-propelled craft. One effect vibration may produce on the eye is resonation at its own frequency of about 40 cycles per second. However, it is more likely to be produced

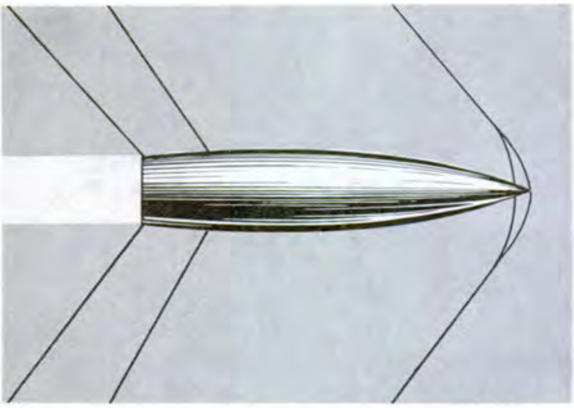


Figure 8–2. (Byrnes) Projectile Moving at a Speed of Mach 1.31 (1,000 MPH).

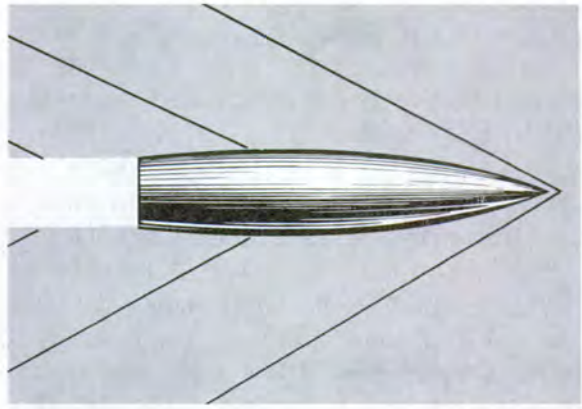


Figure 8–3. (Byrnes) Projectile Moving at a Speed of Mach 2.63 (2,000 MPH).

by low frequency vibrations of 10 to 40 cycles or 60 to 90 cycles than by high frequency vibration.

LAG IN VISUAL PERCEPTION

The length of time between an occurrence and the time a person sees it depends upon two factors: The length of time required for light to reach the eye, and the conduction time in the visual pathways and brain tracts. Because the speed of light is so fast, it is an unimportant factor; but the lag in the visual mechanism is appreciable and at supersonic speeds is important.

The latent period of perception varies with the individual, with his state of attention, with the part of the retina stimulated, and with the intensity of the stimulus. It may vary from 0.035 to 0.300 seconds. Sensory conduction times are important at supersonic speeds because of the distance travelled—for example, an individual flying 1,800 miles per hour is travelling approximately a mile every 2 seconds.

From the time an object appears in the peripheral visual field until the object is seen by central vision, about 0.400 second will have elapsed and the aircraft will have travelled 1,042 feet. At this point, the person has only seen the object—it has not been recognized.

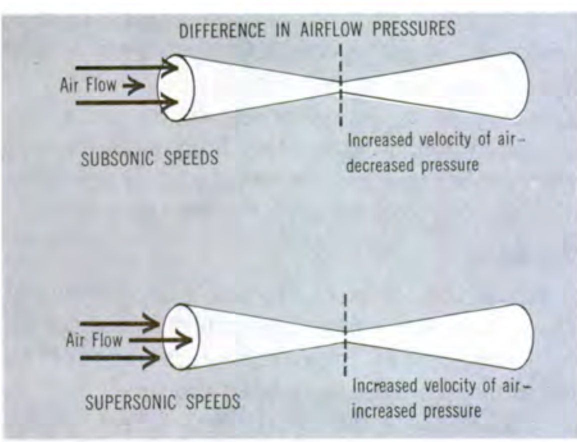


Figure 8–4. (Byrnes) Behavior Characteristics of Air at Subsonic and Supersonic Speeds.

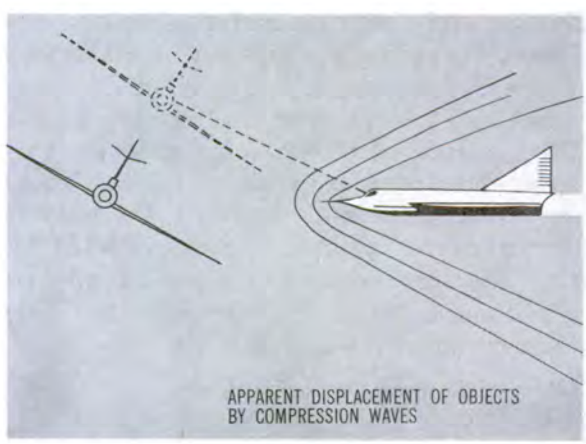


Figure 8–5. (Byrnes) Visual Effects Produced by Shock Waves.

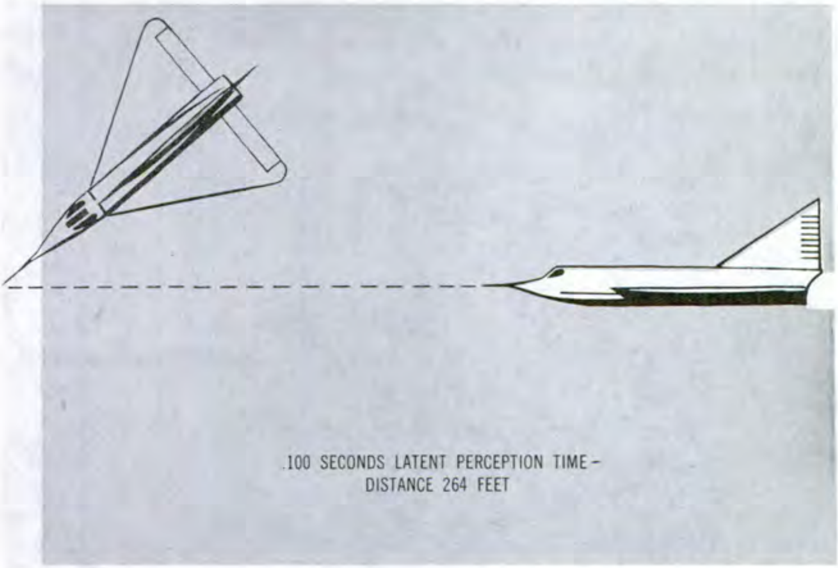


Figure 8–6(A). (Byrnes) Latent Perception Time at 1,800 Miles Per Hour.

If an object appears in the visual field it will be roughly 0.1 second before the pilot is aware that an object is present. During this period he will travel 264 feet.

Recognition time varies between 0.65 and 1.50 seconds, so an average would probably be 1.0 second during which time an additional 2,640 feet will have been travelled.

This means that from appearance to recognition the plane has travelled 3,683 feet. The time required to make a decision to do something about it and the motor reaction time to move control surfaces is not included. Obviously, therefore, if two aircraft came out of the clouds 3,000 feet apart and were coming toward each other, they would collide before the pilots could do anything about it.

To move the eye from clear distance vision to read a dial with recognition and return to clear vision takes about 2.39 seconds. During this time, the plane would move 6,336 feet. The time of accommodation increases with age and is an important factor in selecting pilots for high-speed craft. Because of this high-speed, it is also important that instrument dials be set up for maximum readability (figure 8–6 (A) through (F)).

Lag in visual perception is a very important factor in supersonic aircraft. It is obvious from the above discussion that the human visual apparatus is unable to cope with the demands placed on it by supersonic

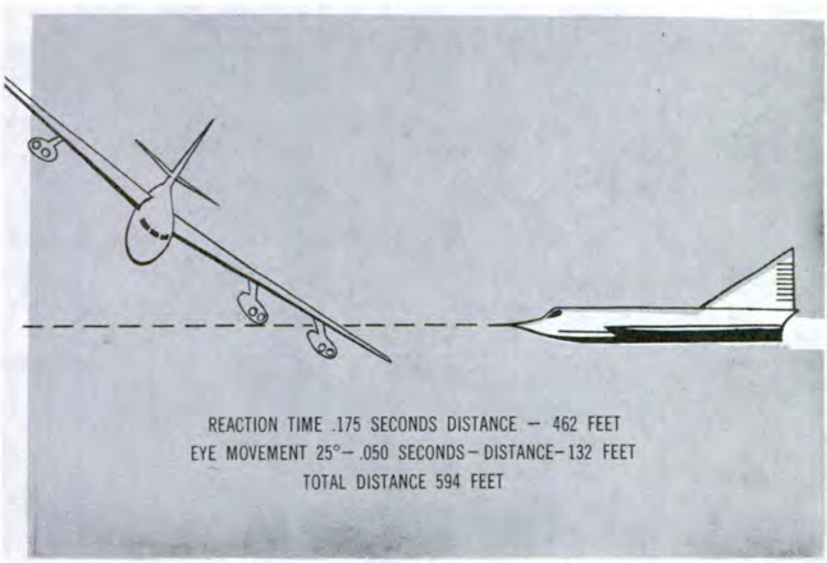
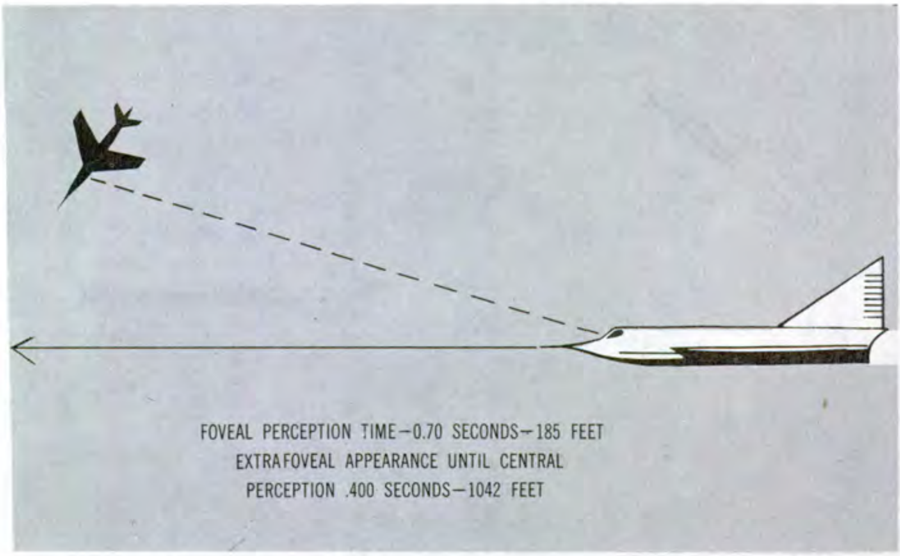


Figure 8–6(B).

After perception of an object in the peripheral field, in order to see it centrally a motor reaction time of 0.175 second is required to prearrange the eye movement. The eye movement itself requires 0.050 second. Distance travelled — 594 feet.

Figure 8–6(C).

After the visual axis is fixed on the object to be viewed, foveal perception requires 0.070 second. Total time, then from extra-foveal appearance to central perception is 0.400 second. Distance travelled — 1,042 feet.



speeds. For this reason, the current century-series aircraft and future aircraft, whether jet or rocket-propelled, will require the use of electronic devices which can detect aircraft or other objects in space before the unaided human eye can possibly see them, and allow the pilot to take offensive or evasive action.

Acceleration

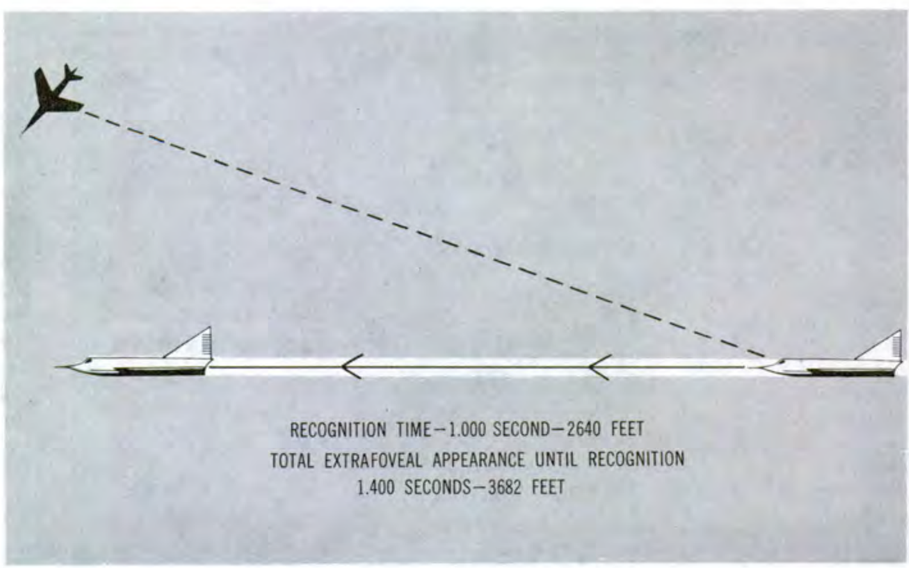
Forces of 6.0 Gs will cause practically every upright observer to black out unless he is wearing a very good G-suit. Turns which produce 6.0 Gs at various speeds have been computed to give an idea of the limiting effect which this phenomenon has on high-speed flight. Turns of the following radii would each produce 6.0 Gs.

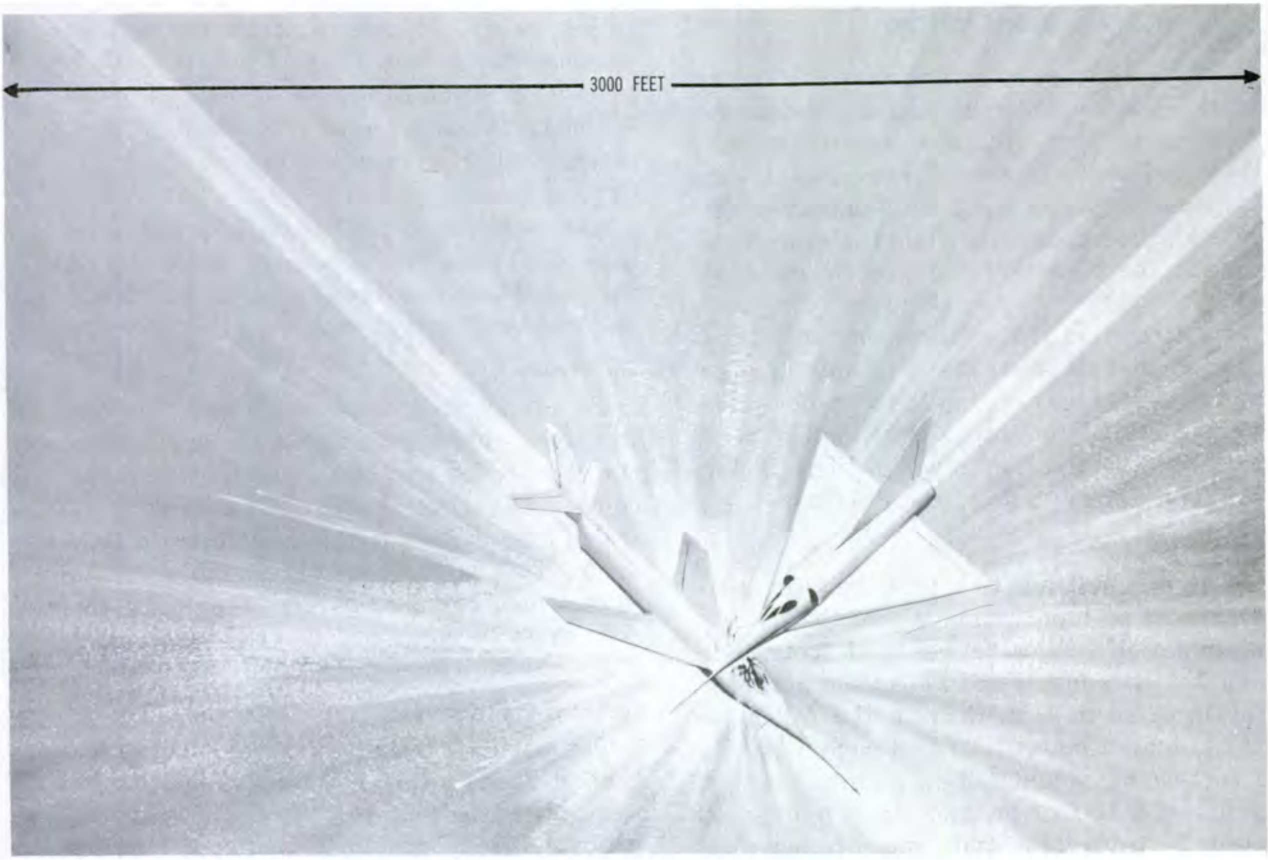
250 mph	686 feet
500 mph	2,740 feet
750 mph	6,170 feet
1,000 mph	11,132 feet
1,500 mph	25,074 feet
2,000 mph	44,530 feet

Thus, at a speed of 2,000 miles per hour the pilot could not turn a circle smaller than 18 miles in diameter. And he would black out all

Figure 8–6(D).

Speed of recognition varies from 0.65 to 1.50 seconds, average about one second.





If two pilots emerged from clouds 3,000 feet apart on a collision course, they would crash before they could do anything about it. If the distance were only 500 feet, they would collide without either pilot seeing the other.

Figure 8–6(E).

the way around the circle unless he were wearing a good protective suit or assuming a position other than upright.

Temperature at Supersonic Speed

Aircraft travelling 2,000 miles per hour can develop a surface temperature above 600° C. Efficient insulation and refrigeration must be used for aircraft to operate at such speed. This is an engineering problem which has been solved in the small satellites sent into space, as well as in the case of the X–15.

The eyes can withstand dry air of at least 240° F which is the highest a human can breathe—an absolute tolerance at 240° F being about 23 minutes. Actually, the eyes can tolerate any temperature which the body can withstand.

Ejection at Supersonic Speeds

There have been several reports of pilots ejecting from aircraft at speeds in excess of Mach 1. The pilots involved suffered severe damage to the body as a whole and to the eyes. At the present time, there is no adequate protection for the eyes on ejections at speeds greater than 550 miles per hour when using conventional helmets. The solution lies in using a closed capsule-type ejection apparatus.

NIGHT VISION

There are two types of sensory end organs in the retina—the rods and the cones. According to the widely accepted duplicity theory of vision, the rods are responsible for vision at very dim levels of illumination (so-called scotopic vision), while the cones function at the higher illumination levels (photopic vision). The cones alone are responsible for color vision. There is a common misconception that the rods are used only at night and the cones only during the day. The cones, as will be pointed out later, function at all levels of illumination down to their threshold. The same is true of the rods.

Mesopic Vision

There is a transition zone between photopic and scotopic vision where the level of illumination ranges between .01 foot-candle and 1 foot-candle. For comparison purposes, the light on new snow from the full moon would measure about .01 foot-candle and the 1 foot-candle would fall on a white sheet of paper at a 10-foot distance from a 100-watt bulb. Both the rods and cones are active at dusk when the level of light spans these limits, and the perception experienced is

Reaction Time	.175	seconds	462 feet
Eye Movement	.050	seconds	132 feet
Foveal Perception	.070	seconds	185 feet
Accomodation	.500	seconds	1320 feet
Recognition	.800	seconds	1952 feet

Figure 8–6(F).

called mesopic vision. Neither the rod or cone network operates at peak efficiency. Central vision would be markedly reduced in the lower right ranges and rod detection capability would be severely hampered at the upper levels.

Below the intensity of moonlight (the cone threshold), the cones cease to function and the rods alone are of value to an individual under these circumstances.

Thresholds

The dimmest light in which the rods can function is about 10^{-6} millilamberts, the rod threshold. The dimmest light in which the cones can function is about 10^{-3} millilamberts which is equivalent to the light from the half moon. This is the cone threshold. A white light which can just barely be seen by the rods must be increased in brightness 1,000 times before it becomes visible to the cones.

Eccentric Fixation

The portion of the retina responsible for keenest visual acuity is the fovea which corresponds to the center of the visual field, and which is used constantly to fixate objects. The fovea is composed entirely of cones. This means that at luminance levels below 10^{-3} millilamberts, a blind spot develops in the center of the visual field (figure 8–7).

Rods begin to appear outside the macula and gradually increase in numbers, finally reaching their maximum concentration at a point some 20° from the fovea. Since the rods have a much lower threshold than the cones, they are much more sensitive to light. A person attempting to see in illumination dimmer than moonlight has to depend entirely on his rods. To utilize the rods under such circumstances, the individual must look slightly to one side, above, or below any object which he wishes to see. This is known as *eccentric fixation.*

Proper indoctrination is, therefore, essential for maximum use of vision at night. Men are taught to look slightly above, below, or to either side of a night target, and to employ a roving gaze. Training and repeated practice is necessary in this maneuver if the flier is to use his visual powers to their fullest extent during operations at night (figure 8-8).

Dark Adaptation

Both the rods and cones contain photochemical substances which are bleached on exposure to light. This process of bleaching is thought to initiate visual impulses in the retina. The photochemical substance in the rods is visual purple or rhodopsin; in the cones it is believed to be visual violet or iodopsin. These substances are broken down or bleached by light. During "dark adaptation" there is a maximum regeneration of the photochemical substances.

The rods and cones differ in their rate of dark adaptation, the rods requiring some 30 minutes or longer in absolute darkness to attain almost their maximum sensitivity after exposure to bright light, while the cones attain maximum sensitivity in about 8 minutes. The amount of light energy absorbed by visual purple determines the extent to which it is bleached. An intense light will bleach it fairly rapidly and completely while a dim light will bleach it to a small extent only. In the light-adapted retina, sensitivity to light is diminished.

Photochromatic Interval

Visual purple does not absorb light of a wavelength greater than about 650 millimicrons (the red portion of the visible spectrum). The rods contain visual purple and are almost completely insensitive to red lights. This is not true of the cones. This fact is easily demonstrated. If the intensity of a red light is slowly decreased until the cone threshold is reached, not only the color red but the light itself will disappear. If the same procedure is repeated with any color except red—*for example,* violet light—the violet color will disappear at the cone threshold, but the light will still be perceived by the rods as grey, or dim white light.

If the intensity is further decreased until the rod threshold is reached, the light will disappear entirely. The difference between the level of illumination at which the color of a light disappears (the cone threshold) and that at which the light itself disappears (the rod threshold) is known as the *photochromatic interval.* There is a photochromatic interval for every color of the spectrum except the longer wavelengths of red.

PRACTICAL PROBLEMS IN NIGHT VISION

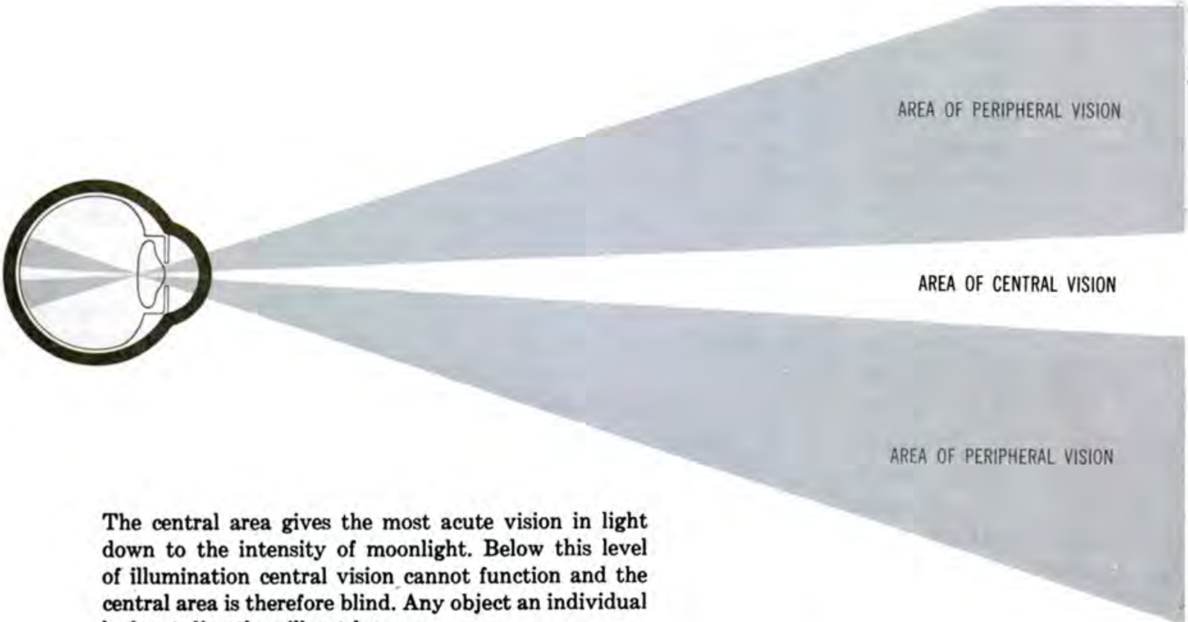
Contrast Discrimination. Objects are seen at night only by being either lighter or darker than their backgrounds. These contrast differences are reduced by light reflected from windshield or goggles, by fog or haze, and by scratched or dirty windshield or goggles. Any transparent medium through which the flier must look should, therefore, be spotlessly clean for night operations. Contrast differences are used by pilots to aid in the discovery of enemy planes while hiding their own ships. Hence, when flying over dark areas, such as land, they should fly below the enemy; when flying over white clouds, desert, moonlit water, or snow, they should fly above the enemy.

Under conditions of low illumination, additional aid may be obtained by following enemy planes either from above or below rather than from directly behind. The retinal image is much larger from the former positions than from the latter and there is less likelihood of losing the enemy in the darkness.

Night Myopia. A person who may be otherwise emmetropic will have a shift toward myopia when under extremely reduced illumination. The exact cause of this myopia is still controversial, but there is good evidence to show that it is made up of two components: a portion due to spherical aberration produced by the widely dilated pupils, and a portion due to slight involuntary accommodation. These portions apparently vary in their importance with different people. Regardless of the cause, it does exist and must be considered in night operations.

The largest group of persons will have about .75 diopters of night myopia.

Preservation of Dark Adaptation. Even in modern warfare, circumstances can arise which may require maximum utilization of night vision. If 30 minutes are spent in a



The central area gives the most acute vision in light down to the intensity of moonlight. Below this level of illumination central vision cannot function and the central area is therefore blind. Any object an individual looks at directly will not be seen.

Figure 8–7. Area of Central Vision.

dark room, the pilot's eyes will be satisfactorily dark-adapted. To overcome this drawback, flying personnel are instructed to wear red goggles to facilitate dark adaptation in fairly bright illuminations which does not interfere with their ability to read maps, magazines, or newspapers, and to see others to whom they wish to talk.

To explain why red filters are used to achieve dark adaptation it is necessary to examine the relative positions of the photopic and scotopic luminosity curves on the wavelength scale of the spectrum. If a filter with a cutoff at about 620 millimicrons is used, a greater portion of the scotopic curve (rod) is eliminated as compared to that portion of the photopic curve (cone) that is eliminated. In effect, approximately 1/10 of the light reaching the cones is effective on the rods.

In other words, for white light to be made equal in brightness to the red light transmitted through the red filter, the white light would have to be reduced to 1/10 its intensity. The cones will become dark-adapted in about 8 to 10 minutes after a pilot steps into the dark, while his rods, by virtue of the red goggles, are already fully adapted. On a dark night, the cone adaption is unimportant since they are incapable of functioning in starlight illumination.

Dark adaptation of the rods develops rather slowly over a period of 30 minutes but can be lost in a second or two of exposure to bright lights. The night flier must, therefore, be taught to avoid bright lights. He must know his airplane so thoroughly that no light is required to locate the controls. He should memorize his route so well that he need seldom refer to his maps. He must keep his instrument panel illuminated at the lowest level consistent with safe operation, and must avoid looking at the exhaust flame or the gun flashes. If he must use light, it should be as dim as possible and used for the shortest possible period.

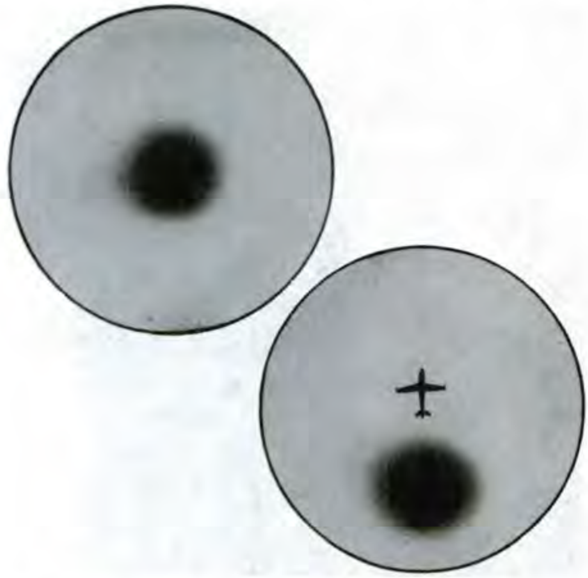
Dark adaptation is an independent process in each eye. Even though a bright light may shine in one eye, the other will retain its dark adaptation if it is protected from the light.

This is a useful bit of information because if a flier must use light for some purpose or is caught in the beam of a searchlight, he can preserve the dark adaptation in one eye by simply keeping that eye closed or by covering it.

Cockpit Illumination. The use of red light having a wavelength greater than 630 millimicrons for illumination of the cockpit is desirable from the viewpoint of dark adaptation. Red lighting of cockpit instruments has been traditional since World War II, and the intent was to retain the greatest rod sensitivity possible while permitting an effective illumination for foveal vision. With the increased use of electronic devices for navigation and enemy aircraft and target detection, the import of man's unaided visual system for these purposes in high-performance aircraft has diminished. Low intensity, white cockpit lighting is presently advocated which will afford a more natural visual environment within the aircraft without degrading the color of objects that are not self-luminous. The disadvantage of red light is that red markings on aerial maps are invisible when viewed in red light.

Ultraviolet light has a disconcerting side effect if directed or reflected into the eye. These radiations produce a fluorescence of the crystalline lens in the eye, giving the pilot the sensation that he is flying in a sea of fog. This annoyance may be avoided by proper adjustment of the ultraviolet lamps and rheostatic reduction of their intensity. These radiations are not injurious to the eyes, for at highest intensities they are still far less than those present in sunlight.

Visibility of Light to the Enemy. Light at the blue end of the spectrum is seen by the rods more readily than any other color; it is not seen as blue but is perceived as light. A blue light just visible to the rods as a colorless light would have to be increased 1,000 times in brightness before it could be seen as blue by the cones, and before any use of central vision could be made. If a pilot exposed himself to blue light bright enough to allow central vision, he would then have lost much of his dark adaptation (rods). Too, the



Left—The central blind spot present in very dim light makes it impossible to see the plane if it is looked at directly.

Right—The plane can be seen in the same amount of light by looking below (as is shown here), above, or to one side of it so that it is not obscured by the central blind area.

Figure 8–8. Eccentric Fixation.

Left—View seen by a person who is not dark-adapted.

Right—The same view seen by a dark-adapted person who is looking at a point above the plane.

Figure 8–9. Dark Adaptation.

Figure 8–10. Night Vision Training Projector, Packed Box.

enemy could pick up a blue light in any position of his peripheral field with ease, whereas a red light of low intensity would be invisible unless viewed directly.

Drugs. The use of drugs systemically to improve normal night vision has been uniformly unsuccessful.

Hypoxia. The effect of hypoxia at altitude on night vision is primarily one of an elevation of the rod and cone threshold. The rise in foveal visual threshold at 4,000 feet is less than 0.05 log unit and at 8,000, it is less than 0.1 log unit. Since the pilot needs vision at the cone levels of adaptation for reading instruments, the actual decrement in acuity from hypoxia is minimal.

NIGHT VISION TRAINING

The use of a number of simulated training exercises form the basis of the Air Force night vision training program. These exercises are given in a completely blacked-out room. The artificial illumination is accurately controlled and adjusted to correspond closely with natural outdoor conditions.

The basic training device now used in the night vision program is termed "The Night Vision Trainer." This instrument is a projector which pictures typical night outdoor activities. They are projected on a screen at levels of illumination found at night. Silhouettes are used so that the various phenomena of dark adaptation and night vision, discussed by the night vision training instructor during the training session, may be practically demonstrated.

For complete details regarding night vision training, reference can be made to AFM 50–10.

REFERENCES

The reader should insure the currency of listed references.

Hecht, S., *Rods, Cones, and the Chemical Basis of Vision,* Physiological Reviews 17: 239 (1937).

Lythgoe, R. J., *The Mechanism of Dark Adaptation: A Critical Resume,* British Journal of Ophthalmology, 24:21 (January 1940).

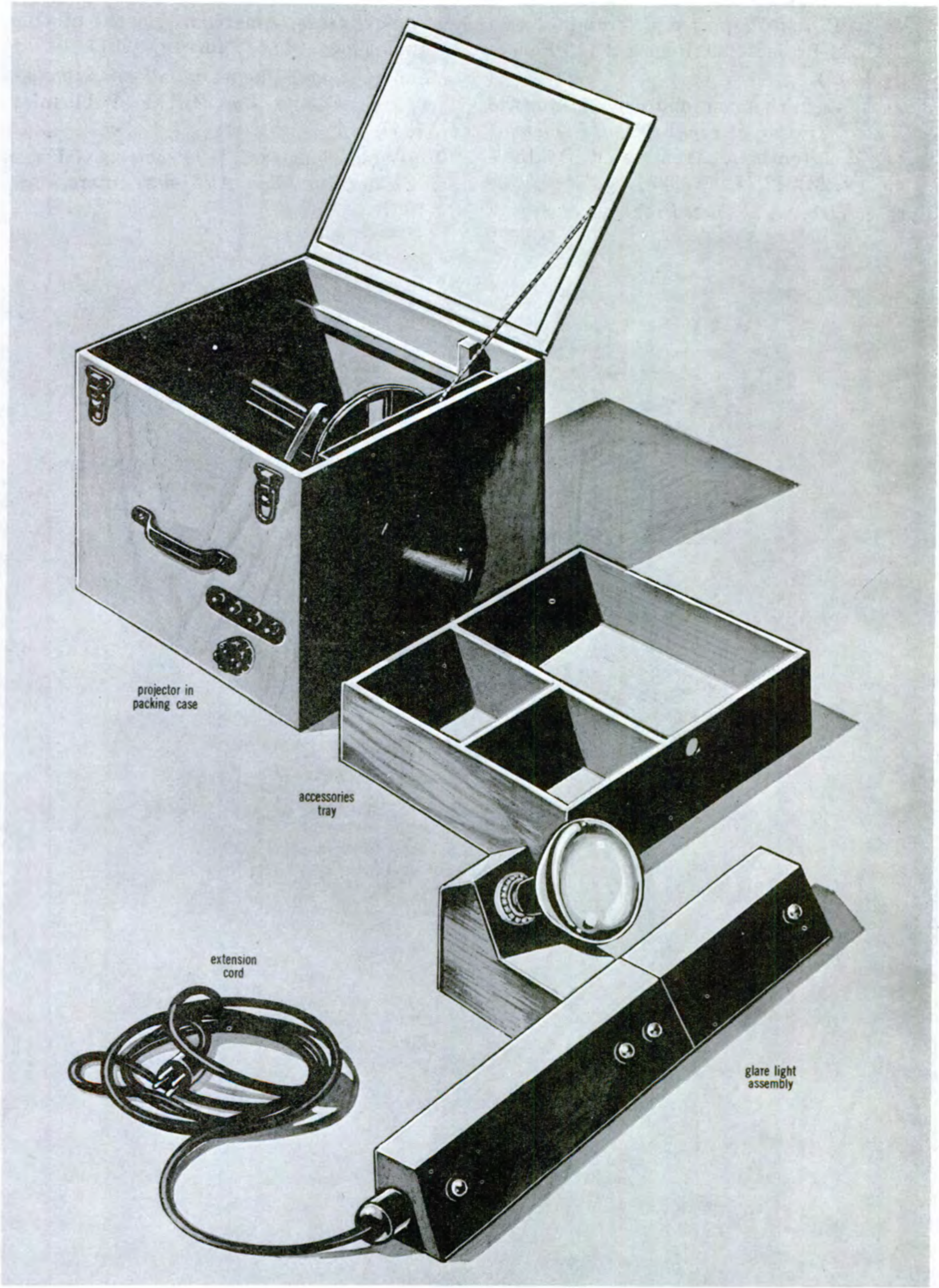
Mandelbaum, J., *Dark Adaptation, Some Physiologic and Clinical Considerations,* Archives of Ophthalmology, 26:203 (August 1941).

McDonald, R., and Adler, F. H., *Effect of Anoxemia on Dark Adaptation of the Normal and of the Vitamin A. Deficient Subject,* Archives of Ophthalmology, 22:980 (December 1939).

RCAF Night Vision Instructors Manual, No. 250. Rowland, W. M., and Mandelbaum, J., *A Comparison of Three Night Vision Testers,* US Air Force School of Aviation Medicine (USAFSAM) Project 213, Report 1 (26 January 1944).

Rowland, W. M. and Mandelbaum, J., *Testing Night Vision,* Air Surgeon's Bulletin, 1:14 (August 1944).

Rowland, W. M., and Sloan, L. I., *Individual Differences in the Region of Maximal Acuity in Scotopic Vision—Application to*


projector in
packing case
accessories
tray
extension
cord
glare light
assembly

Night Vision Testing and Training, US-AFSAM Project 220, Report 2 (19 February 1949).

Sloan, L. L., *Instrument and Technics for the Clinical Testing of Light Sense; Review of Recent Literature*, Archives of Ophthalmology, 22:913 (June 1939).

Byrnes, Victor A., *Visual Problems of Supersonic Speeds*, American Journal of Ophthalmology, 34:2 (February 1951).

Mercier, A. and Duguet, J., *Physiopathology of the Flyer's Eye*, USAF Publication, 1947.

Whiteside, Thomas C. D., *Problems of Vision in Flight at High Altitudes*, Interscience, 1957.

Chapter 9

PSYCHIATRIC DISORDERS IN FLYING PERSONNEL

Psychiatric disorders in flying personnel have been recognized since the days of World War I when it became evident that loss of functional efficiency could occur without any physical evidence to account for it. In explaining this phenomenon at first, the physical aspect was emphasized with little attention being given to the psychological factors that could be of etiological importance.

The various factors adversely affecting the flying ability of a person, were summed up under the title "flying stress." Unfortunately, the symptoms attributed to the adverse factors under flying stress acquired the title of "flying stress"—or "aeroneurosis," "aviation neuroasthenia," "flying fatigue," and so forth. This led to the assumption that a clinical entity had arisèn that was unique to the flying situation, and that anyone exposed to the latter environment might develop this disease.

It is the opinion of many that "flying stress" can best be defined in terms of the special stresses and strains to which flying personnel are exposed. Whether or not the person succumbs to the stresses depends on many variables—the most important being his personality structure. If by reason of distorted emotional development the person suffers from excessive latent anxiety, then, undoubtedly, his ability to withstand stress will be minimal, both in degree and duration.

STRESS, ENVIRONMENT, AND PERSONALITY

Loss of functional efficiency due to emotional factors can best be understood through comprehensive examination of many different factors impinging on each flier. For convenience, the important variables can be grouped into: a. The *Stress* to which the individual is exposed; b. *Environmental Factors* affecting tolerance to specific stresses; and c. specific *Personality Factors,* including inherent adaptability. Whether or not a person loses functional effectiveness because of failure in emotional adaptation depends in large measure on subtle interaction of factors in these three groups. These factors are closely interrelated in actual situations, but for clarity will be discussed individually here.

Stresses evolve from situations which engender fear, insecurity, frustration, pain, fatigue, or any other tension or discomfort. Some situations represent severe stress for everyone, but no situation has an absolute definite quantitative stress value. Stress has meaning only as related to the person who experiences it. Therefore, one must know not only the nature and degree of stress, but also the specific meaning it may have for the person involved.

The ever-present threat of death and mutilation results in a certain amount of inherent stress even in noncombat flying. The degree of this varies depending on the type of aircraft, jet or conventional—the presence or absence of other crew members—the weather—the type of mission and the nature of the terrain underneath. Flying pay and the increased cost of life insurance for fliers reflect these inherent dangers which are but rarely acknowledged consciously by fliers.

In the combat situation, additional factors are, of course, present. In addition to enemy aggressive and defensive action, such factors as anticipation of missions, casualty rates, length of mission tours, injury and death of crewmembers and friends all affect the quantity and quality of stress. During World War II it was discovered that there was a striking correlation between the number of aircraft lost and the incidence of emotional disorders. Appreciable anxiety resulted when the casualty rate was high.

Environmental factors are second in importance only to specific personality factors in effecting a person's tolerance of such stresses both in combat and noncombat flying. These environmental factors include such abstract concepts as *morale, leadership, sense of support,* and *group identity.* The direct and powerful impact of these variables on the person's tolerance to stress is often not fully appreciated. Their importance has long been recognized by military leaders, but their significant implications for aeromedical practice have not been fully appreciated until recent times.

Present concepts of human behavior acknowledge the profound and powerful effect of culture and social attitudes and mores on individual behavior. It has been recognized that the social needs of the person are nearly as strong as his personal needs, and in most cases are closely interwoven with them. Thus, when a person is in a unit where his social interactions produce minimal personal anxiety and frustration and maximum gratification and security, his resistance to stress is greatly increased.

Identifying with a group—developing a sense of "belonging" and loyalty—broadens a person's sense of duty beyond himself to include responsibility to the group. Thus, when the group's mission is clear, the person is willing and able to tolerate more personal stress while pursuing the group goal. The strong cultural restriction against expression of destructive, hostile aggression interferes with achievement of military objectives. One of the important cultural functions of the military group is to establish an atmosphere in which aggression towards the enemy is encouraged and rewarded. When this succeeds, the passive person (whose aggression is ordinarily inhibited by guilt) will be more able to express such aggression.

Aggressive action has a secondary advantage in affording relief of tension and anxiety and thus enhancing a person's stress tolerance. Stressful situations which prevent active aggressive action on the part of the individual are likely to result in increased tension and lessened tolerance for stress. Examples of such situations include making a bomb run through flak, sitting through an air raid, or being grounded by weather instead of flying aggressive sorties. Resistance to stress is reduced under these circumstances.

When a person and/or a group feel that others are doing their fair share and that their efforts and sacrifices are recognized and appreciated, a *sense of support* develops. Such subtle factors as having adequate quarters, good food, recreational facilities, and numerous other "fringe benefits" contribute directly to this sense of support.

Effective *leadership* develops group cohesion and helps define both individual and group roles and responsibilities. It is a key factor in the development of group mores, attitudes, goals, and motivation. Sense of support is largely mediated through leaders.

All of these factors contribute to *morale* which refers in general to the degree of willingness of a group to work towards the group goal. Thus, we can see that all of these environmental factors directly affect a person's ability and willingness to tolerate stress and, accordingly, are quite legitimate, necessary medical considerations.

The personality of the individual upon whom all of these foregoing factors are impinging is, of course, of fundamental importance. If his basic personality structure is sound, with minimal underlying conflict and latent anxiety, then his capacity to tolerate stress will be greater. His basic attitudes toward aggression, regimentation, self-sacrifice and devotion to duty will all affect his performance.

Also significant are: his capacity to identify with a group, his ability to get along with other people, his innate sense of responsibility, and his devotion to principles. These determine *motivation* which is the key factor in determining how much stress a person can or will tolerate. Other important personal factors are age and nutrition, fatigue, and the opportunity for aggressive action and training. The effect of fatigue has been discussed at length in a separate chapter.

By facilitating action, training and education in the use of weapons, in emergency procedures, in self-defense, survival, and escape and evasion tactics, tend to offset the anxiety induced by passivity. Thus, capacity for aggressive action is increased. Education eliminates the doubt and anxiety from unknown and fantasied perils, and replaces it with informed expectation and confidence arising from preplanned offensive and defensive measures.

It can be seen, then, that a wide variety of factors are significant in determining one's resistance to stress and must be considered by the Flight Surgeon if he is to be optimally effective in assisting his fliers in adapting to trying situations. Thus, the role of the Flight Surgeon encompasses not only recognition and treatment of reactions to stress in individual fliers, but also an understanding and analysis of many other factors operating in his unit.

PSYCHIATRIC REACTIONS IN FLYING PERSONNEL

The various psychological reaction types do not differ significantly from those observed in civilian life. They can be described and explained both diagnostically and dynamically by utilizing modern psychiatric terminology and psychopathology. This is particularly true in the early stages of training where the stress is usually minimal.

Despite selection methods, some accepted candidates will show psychological dysfunction in the early stages of their training. Various reaction types are observed, the most common of which are: somatization-reactions including headache, backache, and gastrointestinal dysfunction, anxiety-reactions; conversion-reactions usually related to the special senses (vision and hearing); psychogenic motion sickness; and character and behavior disorders.

Persons whose symptoms occur early during training or without any unusual environmental stresses, will often be found to have immature or passive behavior patterns which have predisposed them to emotional disturbances. They may have embarked on a flying career to prove masculinity or deny a deep-seated need for dependence. In most cases, it will be necessary to recommend removal from training since recurrence of symptoms under future stresses is likely.

REACTIONS TO COMBAT

Under the stress of flying hazardous combat missions, the presence of some degree of apprehension and fear is almost universal. In addition, many people suffer from some of the somatic concomitants of this apprehension. The physiologic effects of anxiety, mediated through the autonomic nervous system, include tachycardia, hyperventilation, nausea or "queasiness," diarrhea, urinary frequency, tremulousness, and "startle." The person so affected may feel restless and irritable, and may have insomnia and anorexia. So common are these symptoms that they can be considered "normal" reactions to combat.

Most people, because of their intrinsic motivation, and the supportive aspects of their group's environment, will be able to tolerate their symptoms and operate effectively despite them. However, occasionally, because of an innate reluctance to continue, one will seek removal from the hazardous situation, and will often justify this on the basis of his physical symptoms. He often will have flown only a few missions and will not have been directly exposed to any unduly stressful experience. Such a person is likely to come to the Flight Surgeon with his mind already made up that grounding or hospitalization is necessary.

Some of these men will be able to continue if the cause and mechanism of the symptoms are explained, and if everything about the manner of the Flight Surgeon indicates his underlying attitude that the person should be able to continue in spite of these normal manifestations of his apprehension. If these superficial measures fail, and the individual must be removed from flying, then this should be done *on an administrative basis.* Any other course would tend to undermine the resolve of men who do continue to function despite their fear and discomfort.

Another group of men develop symptoms only later in a tour after having flown a number of stressful missions. They recognize their reluctance to continue, but because of underlying, sound motivation and identification with the group they wish to complete their tours. Thus, they respond well to the superficial measures mentioned above. If chronic anxiety and fatigue have resulted in insomnia, weight loss and other physical manifestations, then the individual may be benefited by supportive measures such as sedatives for a few days or a short "rest and recuperation" leave.

These decisions are best made by the unit Flight Surgeon. If a pilot is evacuated to a hospital for decision, then his ties to his unit are broken and a potent motivating force is lost. Further, a distant medical officer does not have the same identification with the group as the local Flight Surgeon, and the former's understandable sympathy for his unhappy patient may result in the loss, through medical channels, of a pilot who could have continued. The unit Flight Surgeon, by virtue of his being a member of the group, is better able to recognize that the too-easy release of each pilot from his responsibilities would ultimately undermine the group as a whole.

It should be mentioned that an unnecessarily "tough" policy will also be detrimental to group morale. When a person has been exposed to prolonged severe hazard and ultimately becomes incapacitated in spite of basic good motivation and a strong desire to continue, then medical disposition may be indicated. In such circumstances, as other fliers can sympathize with the disabled pilot, a policy that seems to them tough and unsympathetic may also cause deterioration in group morale. The decision about medical versus administrative disposition is usually not an easy one, and calls for mature professional judgment on the part of the physician.

FEAR OF FLYING

The term "fear of flying" is applied to the circumstances in which a flier requests removal from flying duty because he suffers from an incapacitating fear of flying. This request is usually the last of a series of attempts to avoid a particular type of flying duty or assignment which is unpleasant. There may be some underlying anxiety associated with such a request for relief from flying duty, but defective motivation rather than psychiatric disease is the dominant feature. It is the Flight Surgeon's responsibility to determine whether psychiatric illness or lack of motivation is interfering with the flier's performance of duty.

Difficult questions commonly arise when a flier develops incapacitating emotional symptoms (*i.e.*, of such a nature as to represent a threat to flying safety) which seem especially related to flying stress. Are the disabling symptoms related to a "genuine" illness which is interfering with the effectiveness of a conscientious, responsible person who is struggling to overcome his difficulty? Or, is he a poorly motivated, less responsible person who finds the hoped for secondary gain (removal from stress) too appealing to resist by suppressing his uncomfortable symptoms?

To reward symptoms secondary to poor motivation with medical grounding is, of course, grossly unfair to the rest of the group who may be flying with equal or even greater anxiety and discomfort. On the other hand, to "punish" a sincere, devoted flier who has actually had more than he can take is also grossly unfair to both him and the group. In either case, group morale and motivation are likely to be adversely affected.

As was pointed out earlier, one's stress tolerance varies and is dependent on many factors, among which are group pressures and attitudes. Social disapproval of the man may follow voluntary removal from flying status.

Being on flying status, especially at great personal risk and sacrifice, has high prestige value. Such cultural attitudes must not influence medical judgment and confound an already difficult situation. Nowhere is the skill and clinical judgment of the Flight Surgeon more taxed than in this area. Obviously, evaluation of many cases in this group will be difficult, as considerable subjective judgment is necessary to determine how much "is enough" and what satisfactory motivation is.

It should be noted that the presence of emotional symptoms is not necessarily evidence of psychiatric disease but can be and often is a reflection of faulty motivation. Fair and reasonable handling of the individual case must be based on careful appraisal of the stresses, environmental factors, and motivational or personality factors which have contributed to symptom formation.

Handling must be not only in terms of what is best for the person, but also in terms of what disposition will most favorably affect successful accomplishment of the group's mission. The nature of the military mission is such that we must recognize the persistent appearance of emotional reactions in response to flying duty as evidence of poor motivation for flying rather than as the emotional illnesses which they strongly resemble. In practice, the person's needs and the needs of the group are usually quite compatible. This is in part a result of the fact that allowing the poorly motivated person an easy exit from flying duties through medical channels may cause him to have chronic feelings of failure, guilt, and anxiety. Firm but supportive handling often results in early return to flying duties—an outcome which is optimal both for him and group.

PSYCHIATRIC ASPECTS OF MISSILE OPERATIONS

In missile operations, the relative influence of stress and environmental factors upon the individual is somewhat different from that in the flying situation. Stresses that do exist, such as the hazards of explosion, noxious fumes, and accidents, are, in general, less acute and anxiety-producing. Chronic combat tensions, obviously, are unlikely. Environmental factors, on the other hand, are of much greater significance. Remote locations, small stations with few personnel, limited recreational facilities, insufficient and possibly substandard housing are all important variables.

The strategy of deterrence depends upon the awesome destructive potential of our missiles. Should we have to launch them, then our strategy has failed. Ability to operate the weapon system with very short warning is essential for the success of this strategy. The constant vigilance which is necessary demands alert, keyed-up people.

Maintaining such a frame of mind is difficult enough in a hot war where use of the weapon system is imminent. It is a prodigious task to overcome complacency and establish an alert attitude in the cold war situation where the weapon system has failed in its mission if it has to be operated. These factors—remote location, cold war, and lack of opportunity to operate the system—all tend to render an individual more susceptible to impaired efficiency from emotional symptoms.

Furthermore, it has been shown that from 25% to 40% of all missile failures are caused by human error. A sizeable proportion of these errors is due to impaired efficiency from underlying emotional tensions. Momentary lapses of attention, simple mistakes, slipshod and careless work can often be directly traced to emotional pressures.

Thus, counteractive measures as great or greater than those expended in the combat flying situation are needed to insure against significant decrements in operational effectiveness. The Flight Surgeon's efforts should be directed toward both initial elimination and continual screening out of those whose presence is detrimental to the group or may be a threat to security. He should work with command in identifying morale-reducing factors and faulty leadership. He can recommend and show the need for improved living, recreational and transportation facilities.

As much medical judgment is needed here as is required in the combat situation to decide who should be transferred from a remote site. Extreme attitudes—too lenient or too strict—can have a detrimental reaction on the effectiveness of the unit. Thus, the local Flight Surgeon, as in the past, is in the best position to evaluate the individual case and arrange its disposition. This action is not only fair to the person and the group, but maintains group effectiveness at the highest possible level.

REFERENCES

The reader should insure the currency of listed references.

AFM 160–1, *Medical Examination and Medical Standards.*

Armstrong, H. G., *Aerospace Medicine,* Chapter 23, *"Neuropsychiatry in Aviation."* The Williams and Wilkins Company, Baltimore, 1961.

Bond, D. D., *The Love and Fear of Flying,* New York: International Universities Press, Inc., 1952.

Glass, A. J., *Psychotherapy in the Combat Zone,* American Journal of Psychiatry, 110:725–731, April 1954.

Grinker, R. R. and Spiegel, J. P., *Men Under Stress,* Philadelphia: Blakiston, 1945.

Mebane, J. C., *Neuropsychiatry for the Flight Surgeon,* USAF School of Aviation Medicine, Randolph AFB, Texas, 1956.

Stafford, Clark P., *Morale and Flying Experience; Results of a Wartime Study,* Journal of Mental Science.

Chapter 10

DENTAL PROBLEMS IN FLYING

In consideration of the over-all health plan for flying personnel, certain dental problems are of importance to the success of the Aerospace Medicine Program (AFM 161-2). The Flight Surgeon should be aware of these factors and should bring these dental matters to the attention of the Base Dental Surgeon for his action. Certain general problems may require action by the Command Dental Surgeon.

The Flight Surgeon is required to have a general knowledge of the dental problems confronting the members of aircrews and should be prepared to administer emergency oral medicine when the situation requires it. This section is oriented toward that need.

It cannot be stressed too firmly that the Flight Surgeon must maintain close liaison with the dentists on his base. The Flight Surgeon should always be informed of his aircrew personnel who are being treated by the dentist, and most important, when medication has been prescribed.

ODONTALGIA

Toothaches are usually associated with one of the following:

a. Caries.
b. Tooth crown fractures.
c. Erosion.
d. Acute periapical abscess.
e. Odontogenic infectious processes.
f. Baro-physical phenomena.

CARIES

For convenience, the crown of a tooth is described in terms of five surfaces: the occlusal or biting surface; the lingual or tongue surface; the facial or cheek surface; the mesial and distal, or those surfaces in contact with adjacent teeth.* These surfaces vary in their susceptibility to caries but none is immune to attack (see figures 10-1 and 10-2).

Diagnosis

Accurate localization of the offending tooth is not too difficult, and effective palliative treatment can be provided in an emergency. To obviate serious complications, however, it is important that one be cognizant of the possibility of more involved pathology—e.g., acute abscess or its sequelae.

The patient with a toothache resulting from a carious lesion will usually present the following signs and symptoms:

a. The pain may be intermittent or continuous, but it is always intense.

b. There is a break in the continuity of the enamel surface. In some cases only an enamel shell may remain.

c. The enamel and dentine have a deep brownish-black discoloration.

d. Tapping the tooth with an instrument will usually elicit pain.

If there is further difficulty in determining the involved tooth, thermal tests can be utilized. The principal value to be derived from thermal diagnostic procedures is the observation of variations in response when a normal-appearing tooth is tested along with the suspected offender. For this reason, the clinician should subject an apparently normal tooth to the identical test.

The application of heat and cold to the normal tooth elicits pain, but the response ceases soon after the stimulus is removed. A diseased tooth varies in its reaction to temperature tests. Early inflammatory pulpal changes are present when the reaction to cold persists

* Refer to section on Identification—Dental Records, for detailed description of tooth surfaces.

after application and the tooth responds very little to heat. Advanced inflammatory changes of the pulp are present when the reaction to heat persists after application and the tooth appears to respond very little or not at all to cold.

Procedures:

(1) Isolate the suspected tooth from the saliva with gauze packs.

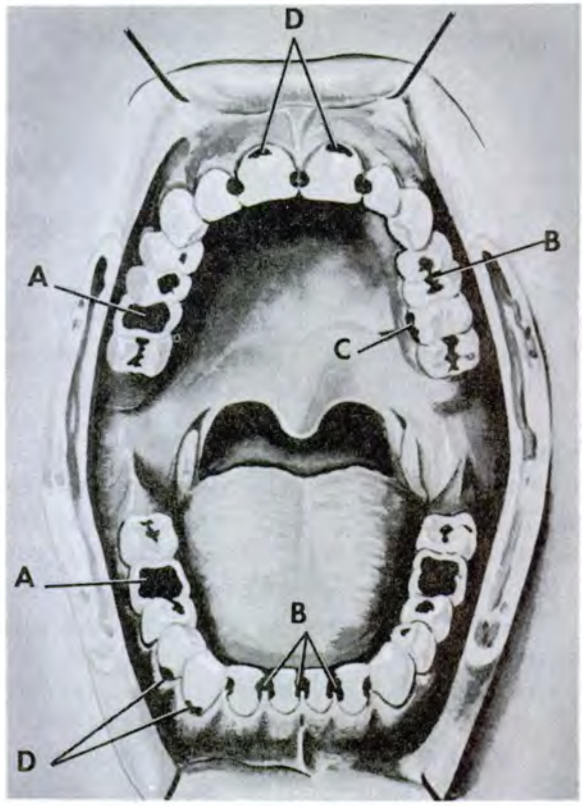
(2) Spray a cotton-tipped applicator with ethyl chloride and place the cold surface on the crown. Ice held in a sponge is equally effective. Note the response and its duration.

(3) Subject the tooth to heat stimulation. Wax or paraffin is softened over a flame and placed on the tooth. If wax is not available, an instrument such as a scalpel handle may be boiled and the tip of this touched against the tooth.

(4) Test an unsuspected tooth as a basis for comparative evaluation.

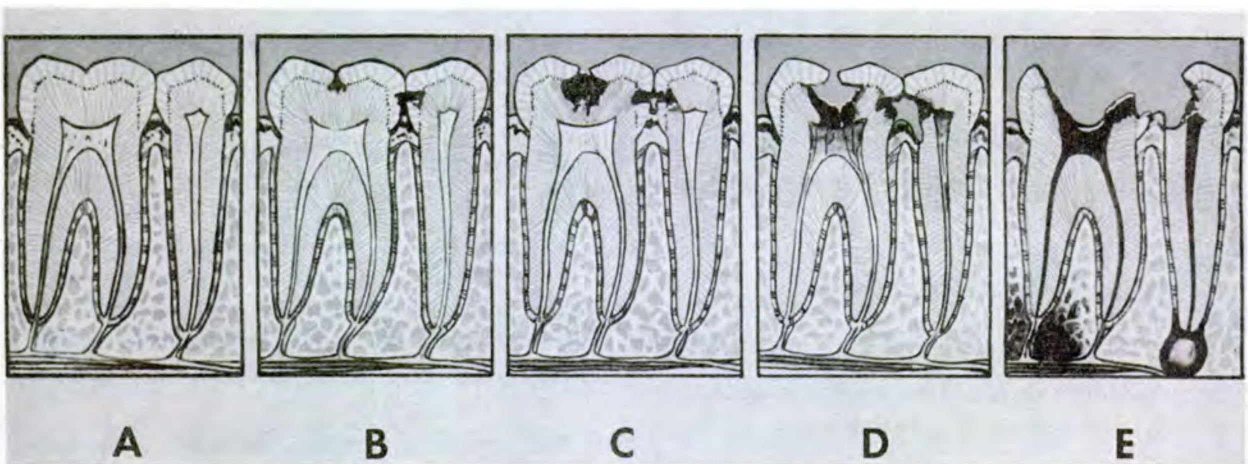
Treatment

After definite localization of the source of pain, a local anesthetic may be employed. This decision rests entirely on the evaluation by the physician.



A. Occlusal cavity.
B. Interproximal cavity.
C. Lingual cavity.
D. Facial cavity.

Figure 10–1. Dental Caries.



A. These teeth are clinically free of caries although a bacterial plague may exist on the surface of the enamel.
B. Cavitation of the enamel has started. This is difficult to observe, but the lesion is detectable in an x-ray.
C. Caries has invaded the dentin and is approaching the pulp.
D. Early pulpal involvement.
E. The crown of the tooth is destroyed; the pulp is necrotic.

Figure 10–2. Progression of Dental Caries.

Figure 10–3. Removal of Carious Material.

Figure 10–4. Drying of the Cavity.

a. Remove the soft decayed material with a spoon-shaped instrument (see figure 10–3).

b. Since these large carious lesions frequently approximate the pulp, considerable caution must be exerted to avoid penetrating the pulp chamber. Remove only the soft decayed material within the cavity of the tooth.

c. Irrigate the cavity with warm water until loose debris has been flushed.

d. Isolate the tooth with gauze packs and gently dry the cavity with cotton pledgets (see figure 10–4).

e. Moisten a cotton pledget with eugenol (oil of cloves), remove the excess medicament by blotting, and wipe over the entire inner aspect of the cavity. A thin film of the anodyne is sufficient.

f. If zinc oxide powder is available, a sufficient amount is spatulated into two or three drops of eugenol to form a thick paste. The mixing can be accomplished on a clean, dry surface. The cavity is then filled with the zinc oxide-eugenol ointment (see figure 10–5).

g. Relieve possible interference with opposing teeth by asking the patient to bite several times. Surplus filling material is easliy removed and surface contour of the restoration established by light pressure with a moist cotton pledget. The pain will disappear in a few minutes and the paste will harden within 2 hours. Caution the patient not to use the treated tooth in masticatory function for the next 24 hours.

Figure 10–5. Placement of the Temporary Filling.

h. If zinc oxide powder is not available, the cotton pledget impregnated with the liquid anodyne can be left in the cavity.

i. Instruct the patient that the procedure is temporary and that he must be treated by a dental officer.

TOOTH CROWN FRACTURE

The anterior teeth are particularly susceptible to traumatic injuries which may result in fracture of the crown. The classification and emergency treatment for the bulk of these injuries are summarized as follows:

a. Simple fractures of the crown involving little or no dentin (figure 10–6). *Treatment:* Smooth the rough edges of the tooth.

b. Extensive fracture of the crown which involves considerable dentin (not the pulp) (figure 10–7). *Treatment:*

(1) Wash the tooth with normal saline.

(2) Isolate and dry the tooth.

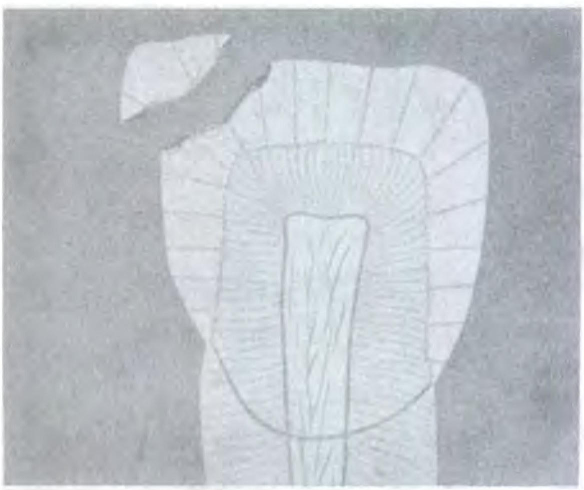


Figure 10–6. Simple Tooth Fracture.

(3) Cover the exposed dentin with a zinc oxide-eugenol ointment, or a thick paste of calcium hydroxide and sterile water.

c. Extensive fractures which involve the dentin and expose the pulp (figure 10–8). *Treatment:*

(1) Isolate and dry the tooth.

(2) Wash with normal saline.

(3) Cover the pulp and dentin with calcium hydroxide paste. Zinc oxide and eugenol may be used if calcium hydroxide is not available.

Figure 10–7. Extensive Tooth Fracture.

Prompt definitive dental treatment is essential to the survival of many of these teeth.

Clinical complications in excess of those described above will probably result in the extraction of the tooth if the patient is to obtain relief from pain. Here again the physician's evaluation, the facilities available to him, the feasibility of air-evacuating the patient to the dentist, etc., are factors that cannot be outlined.

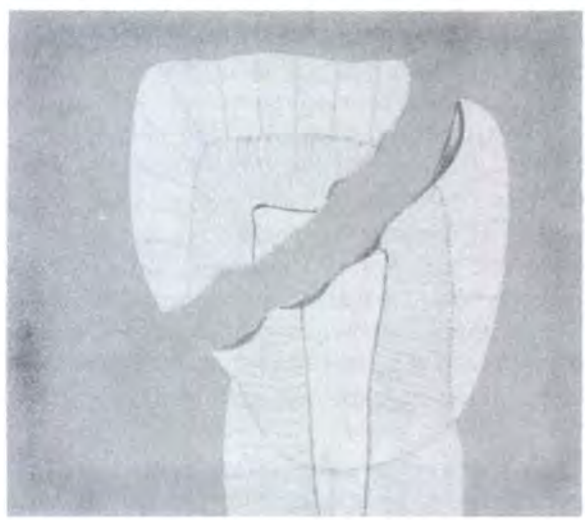


Figure 10–8. Severe Tooth Fracture.

Figure 10–9. Cervical Erosion of the Teeth.

EROSION

Erosion is the progressive loss of enamel by an obscure chemical process without action of bacteria. These lesions usually occur on the facial surfaces of the teeth near the gingival border. Erosion gives rise to pain as a result of exposure of the dentin. Sensitivity increases as more of the dentin is exposed.

The involved surfaces of the tooth will be hard, smooth, and polished in appearance. Extreme pain may be felt in these teeth; they are abnormally sensitive to any kind of irritation. Sweets of any sort as well as thermal changes often initiate a painful episode. Air passing over the eroded surfaces will frequently cause considerable pain (see figure 10–9).

Gingival recession results in an exposure of the surface (cementum) of the root. The treatment of the cemental lesion is the same as that described for erosion.

Diagnosis and Treatment

a. Isolate the eroded teeth with gauze packs.

b. Gently tease the suspected surface with a sharp exploring instrument. The patient will feel a brief pain. A light spray of air will also set off a pain response. These unpleasant yet necessary procedures must be carried out as adjuncts in the proper diagnosis.

c. Local anesthesia is not required.

d. A 2% solution of sodium fluoride or a 33% sodium fluoride paste applied to the eroded surfaces gives relief. Dry the involved tooth surface with a wisp of cotton prior to the application of the drug. The sodium fluoride solution is applied in the following manner:

(1) Place a few drops of the solution in a glass vessel.

(2) Moisten a small pledget of loose cotton with the sodium fluoride solution. Wipe carefully over the dry eroded surface and permit the solution to dry.

e. The sodium fluoride paste may be applied to either the anterior or posterior teeth in the following manner:

(1) Shape the tip of a wooden applicator to a flat edge and dip this in the paste. (A wooden match works equally well.)

(2) Two minutes should be spent briskly

Figure 10–10. Acute Periapical Abscess.

burnishing the moistened wood tip against the dry, eroded surface.

(3) Repeat steps in e(1) and (2).

It may be necessary to repeat these procedures at subsequent visits.

ACUTE PERIAPICAL ABSCESS

This condition results when an infection of the pulp reaches the apex of the tooth and involves the periodontal tissues.

Diagnosis

a. The patient will give a history of repeated episodes of pain that has gradually become more continuous and intense.

b. The accumulating pus causes increased pressure and the tooth will feel elongated to the patient. It will seem to be the first tooth to strike its antagonist when the teeth are brought together.

c. There is severe pain on percussion. This is a most significant sign.

d. A fetid odor may be detected from the breath.

e. Malaise, anorexia, and an elevated temperature are sometimes noted.

f. The regional lymph nodes may be involved.

g. A cellulitis may be evident.

h. Tenderness and erythema are usually characteristic of the gingival tissue around the tooth.

i. Characteristically, an untreated periapical abscess burrows through alveolar bone, and at this stage of progression, is manifest clinically as a bright red elevation of the mucous membrane.

Treatment

The provision of drainage, either spontaneous or induced, usually provides immediate relief from pain. Two methods may be utilized to accomplish adequate drainage:

a. Incise the fluctant area of the soft tissue associated with the acute infection.

b. Establish drainage from the tooth: Stabilize the tooth firmly with the fingers while the soft decay is removed with a spoon-shaped instrument. With a small probe, carefully create an opening into the pulp chamber. Digital pressure on the gingiva near the root of the tooth should force an exudation of pus through the chamber opening. Pain will subside immediately (see figures 10-3 and 10-10).

ODONTOGENIC INFECTIOUS PROCESSES

If the spreading odontogenic infectious process produces a cellulitis which tends to become circumscribed and suppurative, a soft tissue abscess is produced. Since the acute periapical abscess is the most frequent entity leading to this process, an outline of the usual pathogenesis of this condition is indicated. The common course of an untreated acute periapical abscess is as follows:

a. Accumulation of pus and invasion of alveolar bone at the apex of tooth.

b. Invasion of marrow spaces and destruction of trabeculae (suppurative osteitis).

c. Destruction of the cortex and displacement of the periosteum by suppurative material (subperiosteal abscess).

d. Rupture of the periosteum with resulting gingival swelling (parulis).

e. Spontaneous drainage by rupture of the parulis.

This chain of events can usually be halted at any of the stages of progression by removal of the etiologic factor. Extraction of the offending tooth is often indicated. If, however, treatment is not given, spontaneous drainage, while affording welcome relief to the patient, does not suffice. The acute process is then converted to a chronic abscess state that is subject to further exacerbation even though the opening of the sinus tract appears well healed and the patient relatively symptom-free.

The spread of the primary periapical abscess is usually in the direction of least resistance. As a general rule, it may be stated that the cortical bone in closest proximity to the abscess site will be the point of breakthrough. Positively identifying the involved tooth by its proximity to the subperiosteal abscess or parulis is an unreliable procedure. Certainly, a tooth should not be extracted without further diagnostic evidence.

Anatomic considerations play a large part both in determining the path of progression and the possibilities of serious sequelae resulting from further spread of the infective process. The following general statements may be safely made:

(1) Periapical abscess spread is usually toward the lateral aspect of the jaws.

(2) If the primary infection involves the palatal root of an upper tooth, the soft tissue abscess is usually found in the palate. Palatal roots are present in the upper molars and first bicuspids. Abscesses on all other roots in the maxillary dentition tend to burrow through to the facial side.

(3) Abcesses developing on the lingual surface of the mandible at a level producing drainage into the mouth are rare.

(4) Drainage may be manifest other than intra-orally. A periapical abscess may perforate the cortical bone and produce a pathway for drainage that opens onto a skin surface without involving the oral mucosa. The external application of heat promotes this untoward result.

When the spread of a mandibular periapical abscess is directed lingually, the level of bone perforation dictates the course of events. If the breakthrough is above the attachments of the muscles of the mouth, sublingual infection results. If below these attachments, the avenue of spread is through the fascial spaces of the neck. Grave complications such as Ludwig's angina may result.

Treatment

In cases of more advanced progression, the provision of drainage is still of primary import. Antibiotics should be administered and their administration continued for several days subsequent to the remission of symptoms. In soft tissue abscesses, the application of heat is often helpful in localizing the suppuration, but in cases in which the abscess remains within the confines of bone, cold applications to the face are preferable. This is due to the fact that osteomyelitis may result from the application of heat under these conditions if drainage is not provided.

Emergency treatment centers around the prevention of serious sequelae by the provision of drainage, if indicated, and the maintenance of a high blood level of antibiotics. It is highly probable that the extraction of the offending tooth will be necessary, but unless its identification is positive or evacuation of the patient impossible, the final decision on the removal of teeth should be made by a dentist having access to diagnostic aids such as roentgenographic studies, etc.

BARO-PHYSICAL PHENOMENA

World War II, with its emphasis on air power, created considerable alarm among those concerned with aviation dentistry. Some believed high-altitude flying was associated with a new clinical syndrome that included variations ranging from a localized toothache to a complex head neuralgia. Investigators of that period initiated extensive programs designed to determine the effects of flight on the oral structures. The conclusions of these studies, plus the findings of more recent research, indicate that barodontalgia or "altitude induced toothache" is not a new pathologic entity but is a condition intimately associated with preexisting pathology.

Periodontal disturbances, temporomandibular joint pains, habits of lip-biting, grinding, or clamping of teeth, cheek-sucking, etc., have developed in some fliers as a result of occupational tensions, but since toothache is the most frequent dental complaint associated with flight, and is one which responds favorably to definitive treatment, the remainder of this discussion is limited to this problem.

Determining the origin of pain in these cases is many times a most trying ordeal. If the predisposing factors are of dental origin, they usually represent an acute exacerbation of subclinical symptoms, such as a pulp exposure, pulp necrosis, and acute or chronic pulpitis.

Diagnosis

The diagnostic procedures outlined under "Caries" are again recommended. The variations in symptoms preclude dogmatic statements, but the following generalities taken from the literature may be helpful:

a. The offending tooth is likely to be one with a recently inserted filling.

b. If pain occurs during ascent, the tooth is usually vital.

c. If pain persists on the ground, periapical involvement is generally considered as the causative factor.

d. If pain occurred during descent, referred pain from barosinusitis should be suspected. Pain is commonly referred to the teeth from a maxillary sinusitis. The patient complains of dull pain in the area of his upper bicuspids and molars of either one or both sides. Conditions of barotitis media, pericoronitis, and unerupted or impacted third molars may also refer pain to the dentition.

e. A repeated flight or the use of a single chamber flight is seldom helpful is establishing a diagnosis.

f. The patient experiences the one episode and may not have a recurrence of the pain.

Treatment

a. Prescribe an analgesic.

b. If it has been determined that periapical pathology exists, then follow those procedures outlined in the section thereon. Dental disturbances associated with flight continue to be a major research interest of Air Force dentistry. The physician can assist in the evaluation of these cases by reporting his findings to the Base Dental Surgeon or to the Dental Sciences Department of the School of Aerospace Medicine, Brooks AFB, Texas.

SOFT TISSUE PATHOLOGY

The soft tissues of the oral cavity offer a splendid index of the constitutional state of the patient. Among the many readily identifiable conditions in this easily examined area are blood dyscrasias, dehydration, nutritional deficiency, infectious disorders, and the developmental and local alterations. Many systemic diseases present characteristic oral changes during the prodromal stages, thus affording an opportunity for early diagnosis and consequent rapid remedial therapy. Conversely, primary oral disease frequently produces systemic disorders that may be of considerable consequence to the patient. Thus, the mouth offers an immediately accessible, truly reliable diagnostic adjunct to the astute clinician in his search for correct diagnosis.

The great bulk of primary oral soft tissue disorders are chronic in nature and intense pain is not usually characteristic. It is not the purpose of this section to cover the entire fields of oral medicine and periodontal disease but rather to present a discussion of those oral disorders which require immediate treatment by the Air Force physician when a dental consultation is not available. Emphasis will be placed on diagnostic criteria, the temporary alleviation of pain by emergency therapy, and the careful management of those oral lesions which, though not of immediate dire consequence, may assume serious proportions if neglected.

ACUTE NECROTIZING ULCERATIVE GINGIVITIS (VINCENT'S INFECTION)

Chief Complaint

Constant gnawing pain and marked gingival sensitivity are usually the outstanding complaints on admission. These subjective symptoms are characteristically accompanied by pronounced gingival hemorrhage, a foul metallic taste and fetid odor in the mouth, general malaise, and anorexia.

Clinical Appearance

Necrosis and ulceration are the principal characteristics of this exceedingly painful inflammatory disease of the gingival tissues. Necrotic lesions commonly appear between the teeth in the interproximal spaces. These crateriform ulcerations covered by a grayish pseudomembrane are generally pathognomonic. Cervical lymphadenitis and elevation of temperature may develop subsequent to the onset of acute oral symptoms. Untreated lesions are destructive with progressive involvement of the gingival tissues and underlying structures.

Etiology

Although it was felt for many years that fusospirochetal organisms were responsible, the precise etiology has not been irrevocably established. It is now considered by many to be an endogenous infection arising as a result of the action of ordinarily harmless surface parasites exposed to an altered environment. It is beyond doubt that general health, diet, fatigue, stress, and oral hygiene are more important as precipitating factors than are proximity, intimacy, and contamination.

Treatment

The primary problem in therapy is the establishment of good oral hygiene. Simple emergency treatment is outlined as follows:

a. Spray the teeth and gingiva thoroughly with a 1:1 aqueous solution of 3% hydrogen peroxide. Repeat.

b. Instruct the patient to rinse his mouth at hourly intervals with this solution.

c. Place the patient on an adequate soft diet and advise a copious fluid intake.

Institution of the above regimen will usually suffice for the management of the typical acute case. As a result of this treatment, which can be considered by no means definitive, the acute form subsides and the chronic phase ensues. Although clinical symptoms are minimal, tissue destruction continues unabated unless further corrective measures are instituted. For this reason, definitive dental treatment must be obtained as rapidly as possible.

Unless the patient develops systemic manifestations as a result of the oral disorder, antibiotic therapy should not be instituted. Antibiotic lozenges should never be employed in the management of this disease. As in other oral disorders, the use of silver nitrate or like caustics is definitely contraindicated.

Remarks

Lesions similar to those of acute necrotizing gingivitis frequently appear in patients suffering from blood dyscrasias. Any case of gingivitis which does not respond reasonably well within 24 hours requires hematologic analysis.

PERIODONTAL ABSCESS

Chief Complaint

A deep, throbbing, well-localized pain and a tenderness of the surrounding tissues are characteristic. The patient frequently complains that the involved tooth seems elevated in its socket (see figure 10-11).

Clinical Appearance

This acute suppurative process occurring in the periodontal tissues alongside the root of a tooth, and involving the alveolar bone, periodontal membrane, and gingival tissues, usually presents the following signs and symptoms:

a. Redness and swelling of the adjacent gingiva.

b. Sensitivity of the tooth to percussion.

c. Mobility of the tooth.

d. Cervical lymphadenitis.

e. General malaise and elevation of temperature.

Etiology

This condition results from bacterial invasion of periodontal tissues that have been rendered susceptible as a result of irritation from a foreign body, subgingival calculus, or local trauma.

Figure 10-11. Periodontal Abscess.

Treatment

a. Carefully probe the gingival crevice to determine the presence or absence of a foreign body. Foreign bodies must be removed.

b. Establish drainage from the fluctuant area by means of the probe or with an incision made to parallel the long axis of the tooth and to extend to the periosteum.

c. Spread the tissues and irrigate with warm water to remove remaining pus and debris from the abscess area.

d. Instruct the patient to use a hot saline mouth rinse hourly. With definitive treatment, the prognosis is good.

Remarks

The symptoms of a periodontal abscess closely resemble those of a periapical abscess. Because of variations in prognosis, it is important to differentiate positively between the two. Involvement of the lateral aspect of a tooth root by a single lesion, which can be entered from the gingival crevice, is indicative of a periodontal abscess. The presence of suppurative material in the gingival crevice of the affected tooth also points to this diagnosis.

HERPETIC INFECTION

Chief Complaint

Intense pain is the most frequent admission symptom when the fully developed herpetic ulcer is present. Itching, burning, and a feeling of tissue tautness are more characteristic in the earlier developmental stages. Pain on mastication and during the ingestion of acid fluids is especially severe.

Clinical Appearance

Oral herpetic lesions usually appear as localized ulcerations, but extensive involvement of the oral mucosa is occasionally seen. The vesicular stage, so characteristic of involvement of the lips and commissures, is seldom seen within the oral cavity. Intra-oral vesicles are quickly ruptured and the herpetic lesion then appears as a small eroded area with a characteristically bright red, flat, or slightly raised border. In later stages, the lesion becomes covered with an all-white plaquelike mass of epithelial cells, fibrin, and debris.

Generalized herpetic infections produce large areas of fiery red, swollen, and extremely painful oral mucosa. It is in this type that systemic symptoms of toxemia are pronounced.

Etiology

It seems clearly established that the lesions are due to the herpes simplex virus. This virus persists throughout the lifetime of the patient in loci closely approximating the site of primary infection. In an otherwise healthy mouth, a degree of lowered resistance must be present in the oral structures for the virus to produce its pathogenetic pattern. The more frequently observed predisposing factors are emotional stress, the common cold and other upper respiratory infections, gastrointestinal disorders, nutritional deficiencies, food allergies, and traumatic injuries to the oral structures. It is interesting to note that, in females, menstruation and pregnancy often seem to trigger this process.

Treatment

Therapy is primarily palliative in nature. Although there are reports to the contrary, antibiotic therapy does not seem to produce regression of the lesions. Systemic therapy of this type may be indicated in the prevention and control of secondary infection. Palliation is afforded by the following treatment:

a. Dry the ulcer with a gauze pack.

b. Apply tincture of benzoin with a cotton-tipped applicator and allow to dry.

c. Repeat.

d. Instruct the patient to rinse hourly with a warm saline mouthwash.

e. Prescribe a soft diet and encourage copious fluid intake.

This treatment, which should be repeated daily, will afford relief from pain and provide a protective covering for the lesion.

Remarks

In the typical case, healing follows an uneventful course of about two weeks. Scar formation or serious sequelae are exceedingly rare.

The primary infection with herpes simplex virus, usually seen during childhood, produces a much more extensive and serious oral involvement than do the later episodes. Lesions are usually larger and more numerous and, consequently, the pain is greater.

CHRONIC RECURRENT APHTHAE (CANKER SORES)

Chief Complaint

Pain, from the primary lesion or as a result of secondary infection, is the predominant feature.

Clinical Appearance

These lesions—most commonly seen in the buccal mucosa, tongue, and floor of the mouth—are markedly similar to oral herpetic lesions except for the following:

a. The border of the aphthous ulcer is usually more elevated.

b. These lesions tend to produce small scars.

c. Healing is not ordinarily complete in less than 3 weeks.

d. Aphthae tend to recur in groups, and in some instances, the remissions and exacerbations are so definite as to be relatively predictable by the patient.

Etiology

The etiology is unknown. It was formerly felt that this condition was of herpetic viral origin, but the inability to cultivate a virus from these lesions, along with the reported findings that no intranuclear inclusion bodies were present in biopsy specimens, tends to discount this possibility. It has been reported further that there is no alteration in antibody titer against the herpes simplex virus as a result of an attack of aphthous stomatitis.

Treatment

Antibiotics are of no value in the management of the primary lesions but systemic therapy of this nature is, of course, essential if secondary infection ensues. Emergency treatment is identical to that outlined for herpetic lesions.

Remarks

Routine therapy for recurrent aphthous stomatitis is by no means clear cut in definition. Repeated vaccination with cowpox vaccine is said to afford relief in about half the cases. When this therapy fails, complete allergy studies should be undertaken and the patient evaluated as to endocrine status. Although many therapeutic trials have been undertaken, there is no specific definitive therapeutic agent at this time.

PERICORONITIS

Chief Complaint

Marked pain in the area of a mandibular third molar is the most constant complaint on admission.

Clinical Appearance

This acute inflammatory process is manifest in tissue flaps over partially erupted teeth. The clinical picture is that of a markedly red, swollen, suppurative lesion which is very tender and often accompanied by pains radiating to the ear, throat, and floor of the mouth. Excruciating pain is produced when

Figure 10-12. Pericoronitis.

the opposing tooth impinges upon this swollen flap during mastication. Fever and general malaise are usually present. There may be trismus of the masticatory muscles of the affected side. Involvement of the cervical nodes is also quite common (see figure 10-12).

Etiology

Principal etiologic factors include trauma from opposing teeth, accumulation of food and debris, and bacteria and their products.

Treatment

Satisfactory emergency treatment is as follows:

a. Wrap the tip of a blunt silver probe with a wisp of cotton.

b. Dip the cotton in 3% hydrogen peroxide.

c. Carefully cleanse beneath the tissue flap.

d. Apply gentian violet or thimerosal to the area in a like manner.

e. Instruct the patient to use a hot saline mouth rinse hourly.

f. Prescribe a soft diet and caution the patient to refrain from chewing on the affected side of the mouth.

g. Repeat this treatment at daily intervals until the inflammatory reaction subsides.

Remarks

Antibiotic therapy should be limited to the treatment of systemic symptoms. Since extraction of the offending tooth is frequently necessary, and since the inflammatory process is prone to recur, definitive dental treatment will be necessary in many instances.

LOCAL ANESTHESIA

The control of pain incidental to dental procedures may be accomplished by local or general anesthetic methods. Local anesthesia is usually the method of choice.

ARMAMENTARIUM

Local anesthetic agents may be administered intra-orally with either a Luer-Lok or cartridge type syringe. A 25-gage, 1⅞-inch needle is most practical for conduction (block) anesthesia and a 25-gage, 1-inch needle for infiltration. A 2% solution of lidocaine or procaine hydrochloride with epinephrine (1:50,000 to 1:100,000) is commonly employed.

Figure 10-13. Facial Injection.

Figure 10-14. Palatal Injection.

Figure 10-15. Locating the Mandibular Foramen.

Figure 10–16. Inferior Alveolar Lingual Injection.

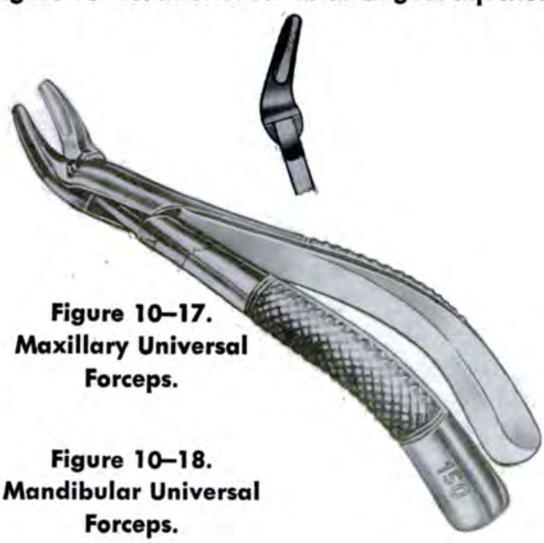


Figure 10–17. Maxillary Universal Forceps.

Figure 10–18. Mandibular Universal Forceps.

MAXILLARY

Infiltration will provide adequate anesthesia of the maxillary teeth. The facial and palatal injections required for effective anesthesia are carried out as follows:

a. *Facial injection:*

(1) Insert the needle into the mucobuccal fold directly above the tooth to be anesthetized. This fold is formed by the junction of the alveolar mucosa with that of the lip or cheek (figure 10–13).

(2) Advance the needle upward for about 3/8 inch, approximately the apical end of the root. Maintain the point of the needle in close proximity to the maxilla.

(3) Slowly deposit 1½ cc of solution.

b. *Palatal injection:*

(1) Insert the needle ½ inch above the gingival margin of the tooth to be anesthetized (figure 10–14).

(2) Gradually expel ½ cc of solution in the submucosal area. After a 5-minute interval, the facial and palatal soft tissues should be tested for reaction to painful stimuli.

MANDIBULAR

Conduction anesthesia, supplemented by infiltration, is the method of choice in anesthetizing the lower teeth. The inferior alveolar nerve is blocked as it enters the mandibular foramen on the medical aspect of the ramus. This foramen is located midway between the anterior and posterior borders of the ramus and approximately ½ inch above the biting surface of the lower molar teeth. The width of the ramus at this level can be estimated by placing the thumb on the anterior surface of the ramus intra-orally, and the index finger on the posterior surface extra-orally. The inferior alveolar and lingual nerve are anesthetized by a single injection (see figure 10–15).

The inferior alveolar-lingual injection is carried out as follows:

a. Place the index finger on the biting surface of the lower molar teeth so that the ball of the finger will contact the junction of the medial surface and the anterior border of the ramus. The fingernail will then be parallel to and facing the sagittal plane.

b. Place the barrel of the syringe on the lower bicuspids of the side opposite that to be anesthetized.

c. Insert the needle at a point ½ inch ahead of the tip of the finger and on a line bisecting the nail. The angulations established by carrying out steps b and c are maintained throughout the procedure.

d. Advance the needle to contact the medial surface of the ramus. One-inch penetration will usually suffice to position the needle point in direct proximity with the mandibular foramen (figure 10–16).

e. Slowly deposit approximately 1½ cc of solution at this point.

f. Withdraw the needle halfway and inject ½ cc of the agent to anesthetize the lingual nerve.

After a 10-minute interval, the results of the injection are evaluated by checking the following subjective and objective symptoms:

(1) Inferior alveolar nerve:

(a) A sensation of swelling and numbness extending to the midline of the lower lip on the injected side.

(b) Insensitivity of the facial gingival tissue in the region of the first bicuspid.

(2) Lingual nerve.

(a) A tingling, swollen, numb sensation extending to the midline of the tongue.

(b) Insensitivity of the lingual gingival tissue.

Anesthesia of the area is completed by infiltrating 1 cc of solution into the mucobuccal fold directly below the tooth to be anesthetized.

TOOTH EXTRACTION

This section emphasizes technics applicable in the majority of cases requiring tooth extraction. Although many types of extraction forceps are manufactured, the removal of any erupted tooth can be accomplished with one of the two instruments illustrated (figures 10–17 and 10–18).

Figure 10–19. Placement of Forceps.

TECHNIC

Use the free hand to guide the beaks of the forceps under the gingival margin on the facial and lingual aspects of the tooth and to support the alveolar process. Apply pressure toward the apex of the root to force the tips of the beaks between the tooth and the alveolar bone (figures 10–19 and 10–20).

Placement should insure a parallel relationship between the beaks of the forceps and the long axis of the tooth. The maintenance of this parallel relationship and apical pressure throughout the process of loosening the tooth will decrease the incidence of tooth fracture.

Exert firm digital pressure upon the alveolar process and the beaks of the forceps with the free hand. This aids the operator in the interpretation of the motion that produces luxation, and protects the teeth in the opposite arch should the tooth suddenly break free

Figure 10–20. Application of Apical Force.

Figure 10–21. Application of Labial Force.

Figure 10–22. Application of Lingual Force.

or accidentally fracture. Rock the tooth with progressively increasing pressure in a facial-lingual direction (figures 10–21 and 10–22).

This force is used for the loosening of multirooted teeth such as molars and upper first bicuspids. Single-rooted teeth are loosened by combining this rocking motion with an alternately reversing rotary force (figures 10–23 and 10–24).

When considerable mobility has been established, deliver the tooth by exerting gentle traction. Note the direction in which the tooth tends to move most easily and follow this path of delivery (figure 10–25).

Inspect the extracted tooth to determine whether root fracture has occurred. Leaving any portion of the tooth, bone fragments, or foreign bodies within the alveolus is highly undesirable and, if deficiencies in the armamentarium preclude their removal, treatment by a dental officer should be sought. Place a folded sponge over the wound and instruct the patient to maintain light biting pressure on this compress for 20 minutes. It may be necessary to repeat this procedure if hemorrhage persists. Caution the patient against rinsing the mouth for at least 12 hours since this may disturb the clot.

POST-EXTRACTION COMPLICATIONS

Two prominent untoward reactions following tooth removal are pain and hemorrhage.

Pain

A moderate amount of pain can be anticipated for a period of a few hours following extraction. This pain is readily controlled by analgesics. Occasionally, a patient will complain of a severe constant, radiating pain that usually begins two to four days postsurgically. Loss of the blood clot, with resultant exposure of alveolar bone, is the most common predisposing factor.

Treatment:

a. Irrigate the socket with warm saline solution.

b. Pack the socket lightly with a strip of ¼-inch gauze. Iodoform gauze saturated with several drops of eugenol and/or guaiacol is ideal.

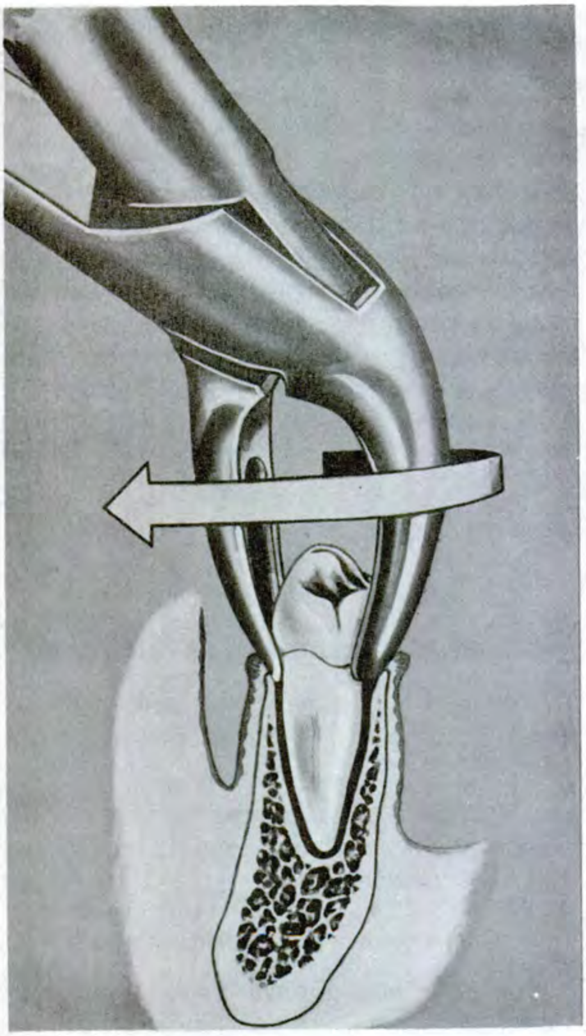


Figure 10-23. Application of Clockwise Force.

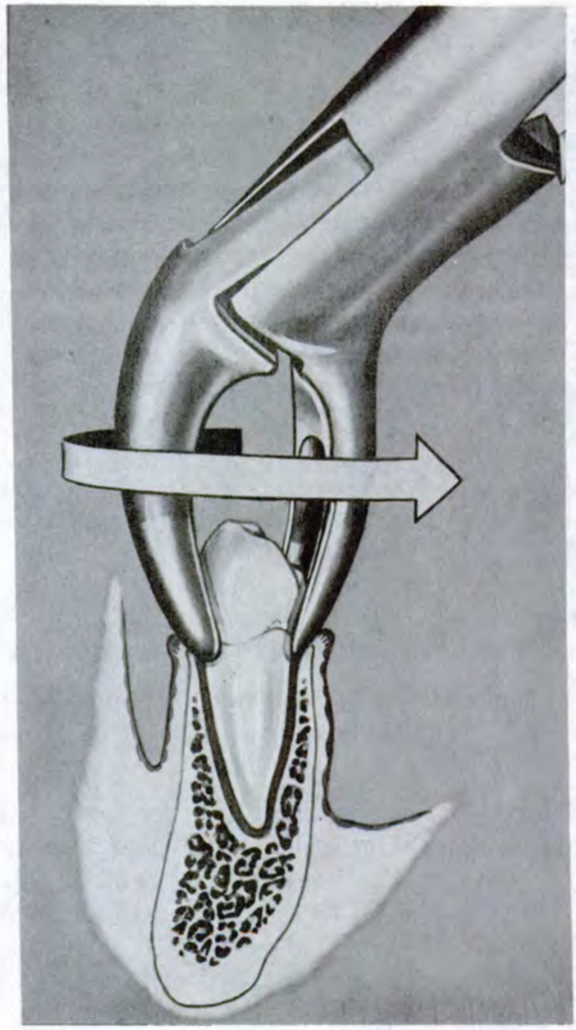


Figure 10-24. Application of Counterclockwise Force.

c. Irrigate and change the dressings daily. Treatment extended over a period of 10 to 14 days is usually necessary.

Hemorrhage

Persistent hemorrhage following tooth extraction can usually be controlled by local measures.

Treatment:

a. Remove the old blood clot.

b. Insert hemostatic agents into the wound.

(1) Fibrin foam or absorbable gelatin sponge with thrombin.

(2) A strip of ½-inch gauze saturated with tannic acid (10%) or epinephrine (1:1,000).

c. Place a gauze sponge over the hemostatic agent.

d. Instruct the patient to maintain light biting pressure on the gauze pack for 20 minutes.

The above procedure may be repeated in order to control hemorrhage.

INJURIES OF THE JAWS

Early temporary stabilization of facial fractures has vital therapeutic implications. This immobilization of the fractured ele-

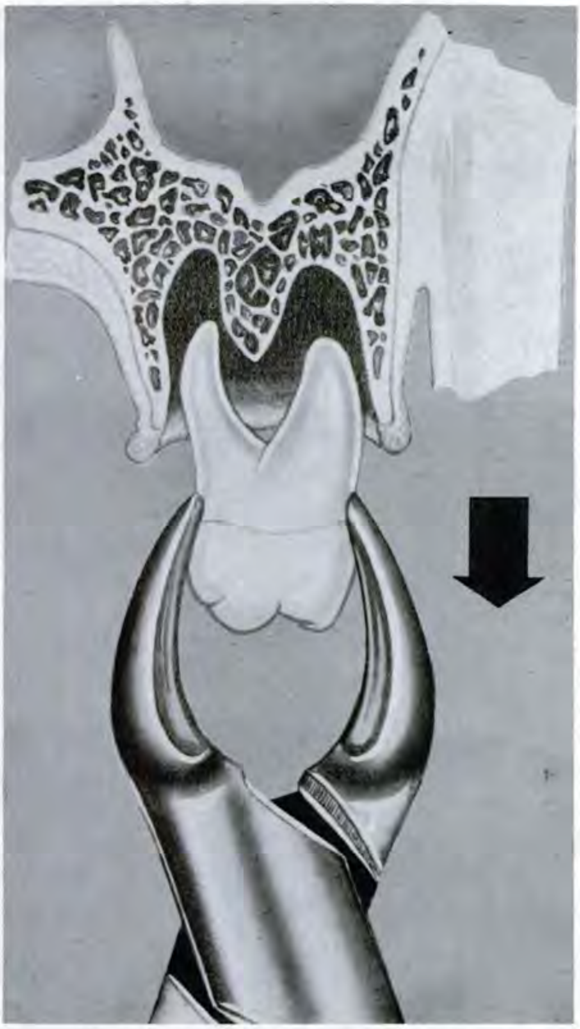


Figure 10-25. Removal of the Tooth.

ments will make the patient more comfortable and will be instrumental in controlling shock, infection, pain, swelling, trismus, and hemorrhage. Furthermore, it has a direct bearing upon the reestablishment of normal function of the masticatory apparatus and on the cosmetic result. The procedures incident to evacuation of the patient for definitive treatment can be carried out more expeditiously and with less resultant trauma when temporary stabilization has been accomplished.

The immediate treatment of facial trauma consists of the establishment of an airway, the control of hemorrhage, the treatment of shock, and the evaluation of neurologic findings. After consideration of these basic therapeutic measures, early temporary stabilization will greatly contribute to the successful treatment of facial fracture.

DIAGNOSIS

This section will be limited to diagnostic procedures and to the presentation of simple but effective technics for the temporary stabilization of jaw fractures. Diagnosis is more difficult when edematous distortion and muscular trismus are present. A thorough clinical examination should include inspection and palpation of the masticatory system for the following:

a. Wounds, swelling, and discoloration.

b. Pain, tenderness, crepitus, and mobility at suspected fracture site.

c. Facial asymmetry.

d. Trismus.

e. Abnormal mandibular excursions.

f. Altered occlusal relationship of the teeth.

g. Segmental alveolar fractures. Pressure should be exerted upon each tooth to determine the integrity of the underlying alveolar bone.

When facilities are available, a radiographic survey should include the following:

(1) Postero-anterior mandible and maxillae.

(2) Right and left lateral oblique of the mandible and maxillae.

TEMPORARY STABILIZATION

The method of choice in attaining temporary stabilization is intermaxillary fixation supplemented by a head bandage for support of the mandible. In maxillary fractures, the intact mandible is used as a splint against which the elements of the maxilla are repositioned and immobilized. In mandibular fractures, the intact maxilla is used as the splint. Although intramaxillary wiring may be accomplished without the use of an anesthetic, local anesthesia may facilitate the procedure. Stainless steel wire of approximately 0.02 inch diameter (26 gage) is ideal.

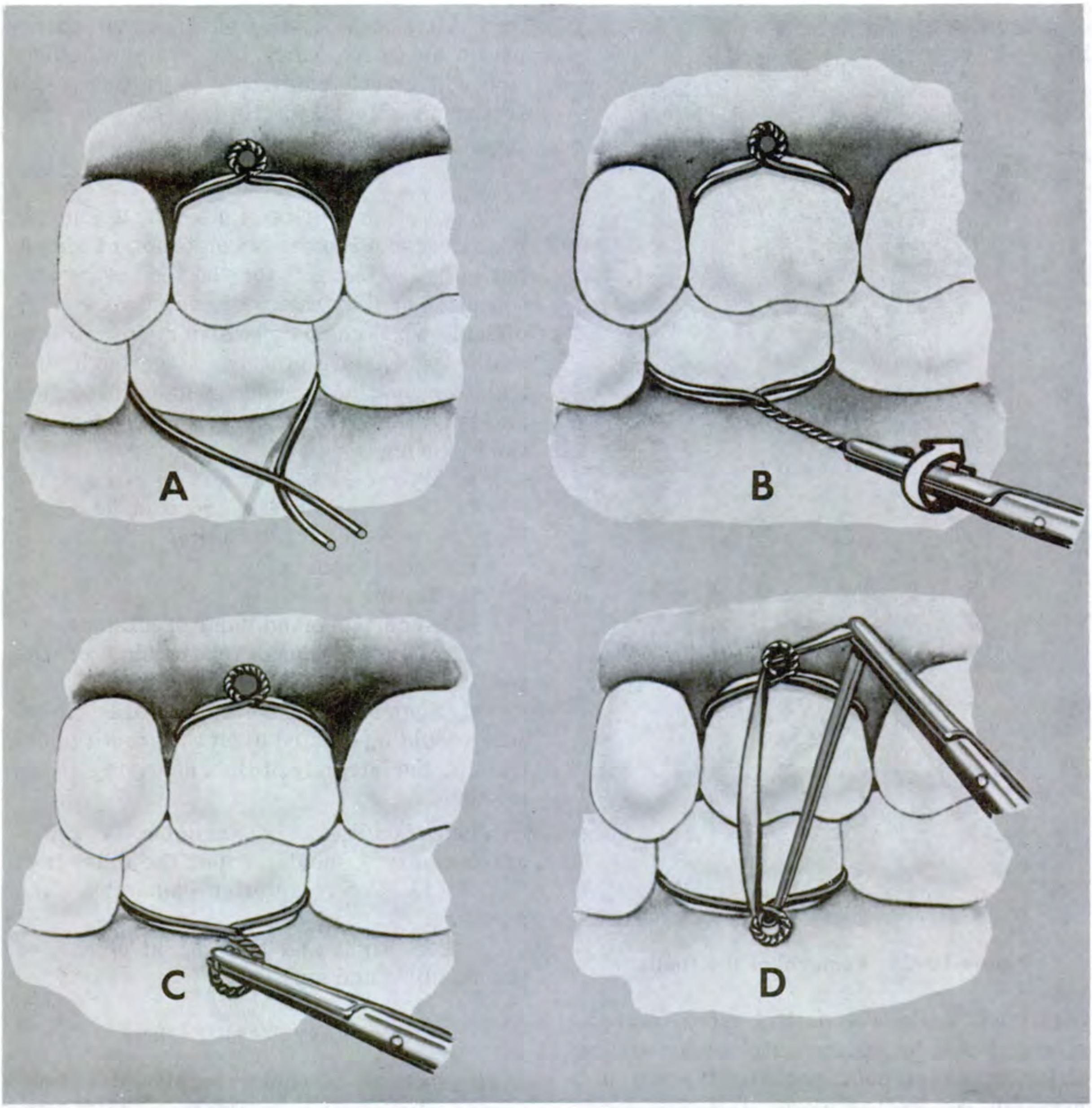


Figure 10–26. Wiring Technic.

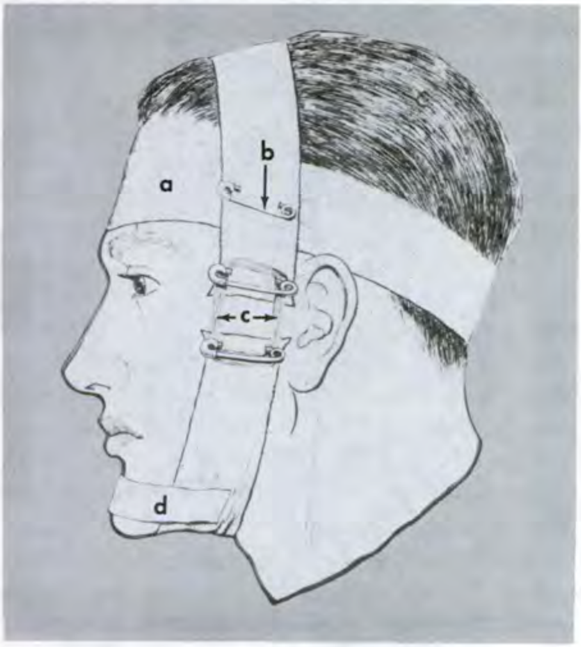
A minimum of two posterior teeth in each quadrant should be selected for wiring. Each of these teeth should be firm and have an opponent in the opposite arch; that is, the biting surface of the upper tooth that is selected for wiring should contact that of the wired lower tooth when the jaws are brought together.

The combined wiring-head bandage technic is carried out as follows:

a. Pass a 2-inch length of wire around the neck of a tooth (figure 10–26(A)).

b. Twist tightly with a hemostat to prevent its slipping over the crown (figure 10–26(B)).

c. Twist the free ends completely.



a. Gauze.

b. Safety pins.

c. Elastic band.

d. Adhesive tape.

Figure 10–27. Supplemental Head Bandage.

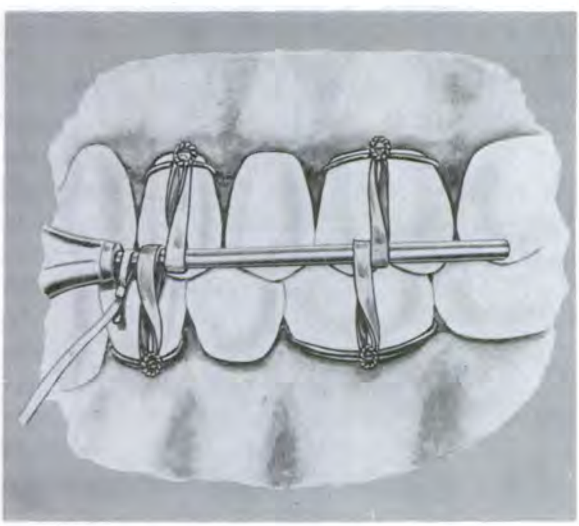


Figure 10–28. Quick Release Mechanism—Modified Cotter Key.

d. Cut the twisted wire ½ inch from the tooth.

e. Form a tight loop with the twisted end (figure 10–26 (C)).

f. Adapt this loop against the gingiva.

g. Form similar loops on all of the teeth selected for wiring.

h. Anchor small intermaxillary elastic bands on these curved loops so that the forces tend to bring the upper and lower jaws together. Elastic loops may be cut from pipette tubing (figure 10–26 (D)).

i. Apply the supplemental bandage (figure 10–27).

EMERGENCY RELEASE MECHANISM

When a marked susceptibility to vomiting is evident, or when the patient is to be evacuated, it is highly desirable to provide an emergency release mechanism which can be activated by the patient or attendant. This procedure is carried out as follows:

a. Blunt the point of a 13-gage needle. (Coat hanger wire serves as a suitable substitute.)

b. Attach a small elastic band to an intramaxillary loop. Pass the needle through the band.

c. Repeat this procedure for alternate loops of the maxillary and mandibular arches.

d. Tie a strong cord to the needle or wire to facilitate its rapid removal (figure 10–28).

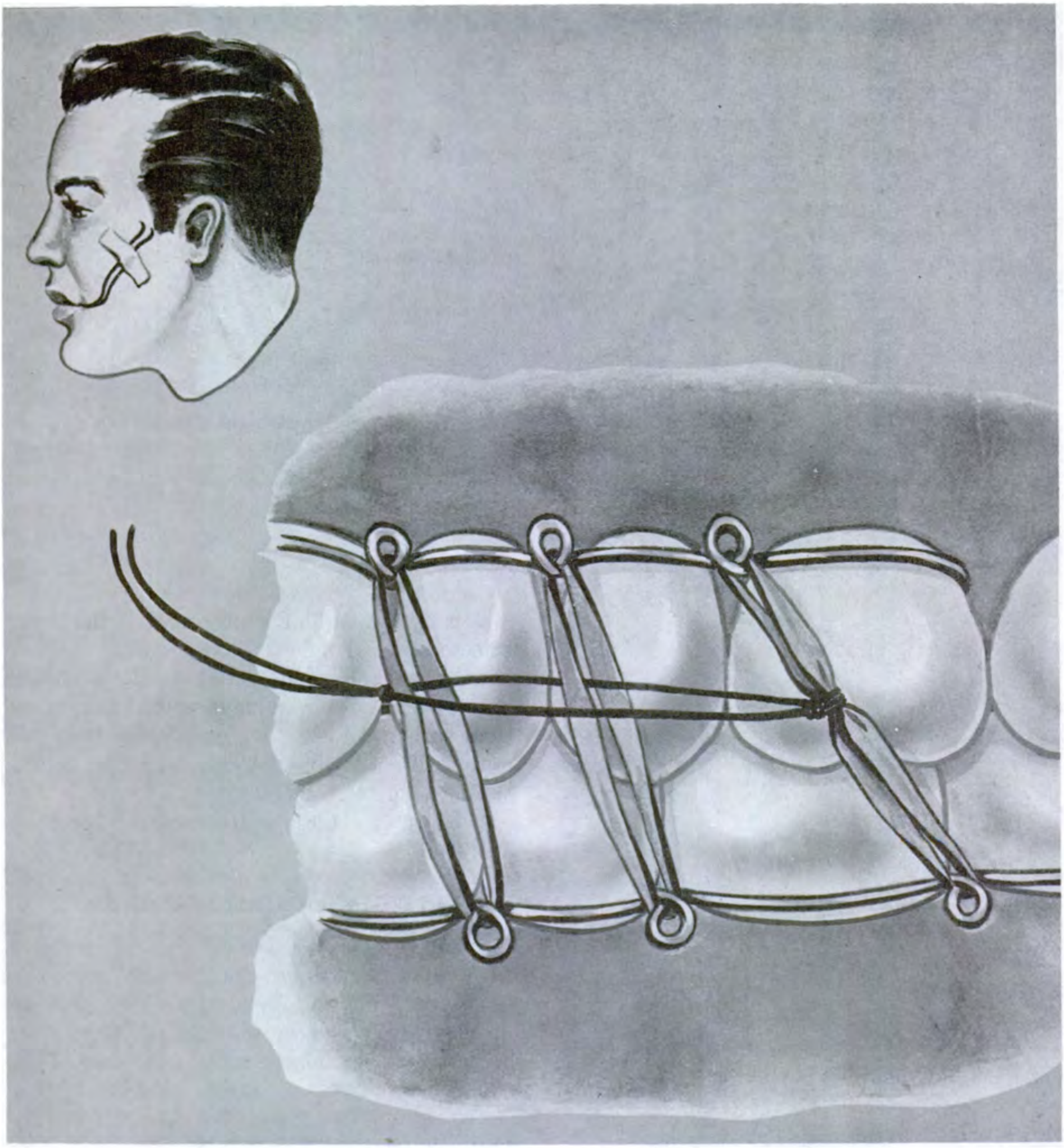


Figure 10–29. Quick Release Mechanism—Rip Cord.

An alternate technic is carried out as follows:

(1) Pass a strong cord through the intermaxillary elastic band.

(2) Tie the free ends of the cord and tape to the patient's cheek (figure 10–29).

Repositioning of fractured elements by judicious manipulation may also be indicated. However, a satisfactory occlusal relationship and a realignment of the displaced bony fragments will usually be achieved within 24 to 48-hours after the application of this gentle intermaxillary elastic traction.

If armamentarium limitations preclude

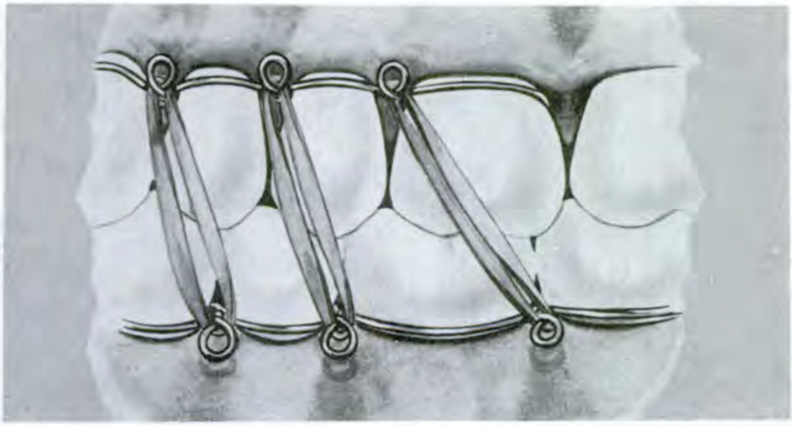


Figure 10-30. Intermaxillary Elastic Traction.

stabilization by intermaxillary traction, head bandage alone may be employed. Although the head bandage is less effective when compared to elastic traction, it is of benefit in providing gross stabilization.

EVACUATION OF THE ORAL FRACTURE PATIENT

The basic problem in the evacuation of the oral fracture patient centers around the fact that the jaws are immobilized. In the majority of these cases, fixation will have been accomplished by intermaxillary elastics (figure 10-30). Occasionally, intermaxillary wires are used (figure 10-31). Provision must be made for the rapid release of either type of fixation. The patient with jaw fixation may experience serious respiratory difficulties resulting from the aspiration of vomitus caused by motion sickness. Careful evaluation and preparation of the patient for evacuation will greatly reduce the incidence of these complications.

Two of the principal features of patient evaluation are:

a. Susceptibility to motion sickness. The attendant should be provided with this information.

b. Type of fixation employed. The problem is more pronounced when intermaxillary wires have been used rather than elastic bands. AFR 164-1 states that patients whose upper and lower jaws are wired together are, normally, not acceptable for air transportation.

Oral and parenteral administration of certain antihistaminic preparations has been shown to be effective in reducing the incidence of motion sickness.

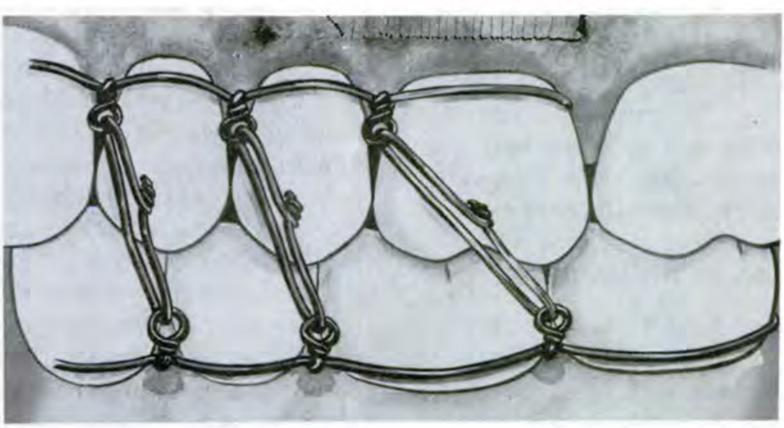


Figure 10-31. Intermaxillary Wiring.

Figure 10–32. Repositioning of Dislocated Mandible (Step 1).

Figure 10–33. Repositioning of Dislocated Mandible (Step 2).

Drugs Effective Against Motion Sickness

	Dose mg. t.i.d.
1. Meclizine	50
2. Diphenhydramine HCl	50
3. Promethazine HCl	25
4. Dimenhydrinate	100

A pair of scissors suitable for cutting wire or elastic should be placed around the neck of each patient. Both the patient and attendants are instructed as to the use of these scissors in releasing the jaws.

In patients evaluated as being markedly susceptible to motion sickness, it is highly desirable to provide a quick release mechanism for the jaw fixation which can be activated by the patient or attendant (see figures 10–28 and 10–29). Dental consultation is particularly valuable in these cases.

DISLOCATION OF THE MANDIBLE

The usual type of dislocation of the mandible is bilateral and the condyles are displaced anteriorly. The mouth is locked open with the chin protruded. Trismus is present and speech is difficult. In the unilateral type, the chin deviates away from the side of dislocation. If a fracture is suspected, radiographs are indicated.

Reduction of the dislocated jaw is normally accomplished without anesthesia. Narcotics are effective in relieving pain and apprehension and thereby prompt relaxation of the jaw muscles. In the more resistant cases, general anesthesia may be indicated.

Repositioning of the dislocated mandible is accomplished in the following manner:

a. Wrap the thumbs with several thicknesses of gauze or towel. This provides protection against snap closure of the mandible.

b. Place the thumbs on the biting surfaces of the lower molar teeth and extend the fingers to grasp the under surface of the mandible (figure 10–32). (The thumbs may also be placed lateral to the molar teeth to prevent their injury.)

c. Exert downward pressure with the thumbs to bring the condyle below the articular eminences (figure 10–33). The fourth and fifth fingers may be used to exert an upward pressure on the symphysis.

d. Maintain this pressure and force the

mandible posteriorly. This will usually return the condyles to normal position (figure 10-34).

e. Caution the patient to avoid excessive opening of the mouth for several weeks.

f. Prescribe a soft diet.

Normally, the pain following repositioning continues for approximately 72 hours. Analgesics should adequately control this pain. If marked pain persists, or if there is a tendency toward recurrence of dislocation, immobilization is indicated. This may be effected by head bandages or by intermaxillary fixation.

Figure 10-34. Repositioning of Dislocated Mandible (Step 3).

IDENTIFICATION—DENTAL RECORDS

In the event of an aircraft crash involving violent forces and fire, or the disrupting forces of modern warfare, positive identification of the dead may be extremely difficult. An accurate dental record of all fillings, missing teeth, prosthetic appliances, bridges and dental anomalies, when compared with a thorough post mortem dental examination will render invaluable assistance in establishing identification. The physician at the scene of the crash may be required to perform the oral examination and complete certain records which are to be compared with existing dental records. Records may be provided which may be referred to, interpreted, and compared with the oral cavity during post mortem examination. This section deals with the performance and interpretation of dental records, SF 603, "Health Record—Dental."

Terminology

Before an accurate evaluation can be made, the examiner must possess certain basic information concerning dental terminology and the materials used in dentistry.

The complete normal human dentition consists of 32 teeth: 12 molars, 8 bicuspids, 8 incisors, and 4 cuspids. These are assigned numbers beginning with the upper right third molar, No. 1, and ending with the lower right third molar, No. 32. The "#" symbol is used before each tooth number or before each series of tooth numbers.

Designation of Teeth

Maxillary—right side		*Maxillary—left side*
#1	Third molars	#16
#2	Second molars	#15
#3	First molars	#14
#4	Second bicuspids	#13
#5	First bicuspids	#12
#6	Cuspids	#11
#7	Lateral incisors	#10
#8	Central incisors	#9

Mandibular—right side		*Mandibular—left side*
#32	Third molars	#17
#31	Second molars	#18
#30	First molars	#19
#29	Second bicuspids	#20
#28	First bicuspids	#21
#27	Cuspids	#22
#26	Lateral incisors	#23
#25	Central incisors	#24

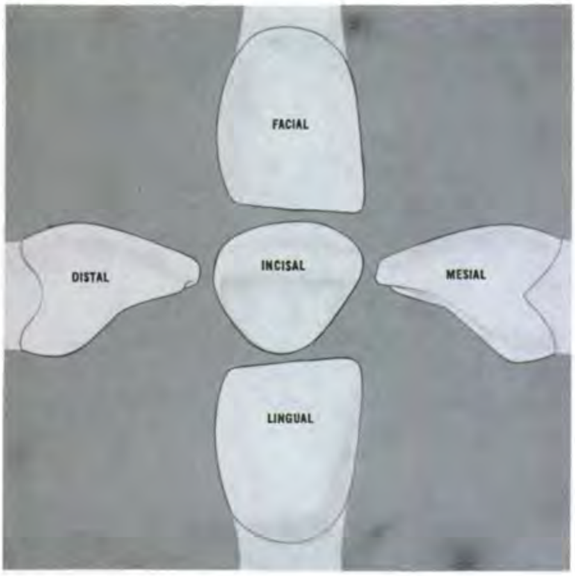


Figure 10–35. Surfaces of Clinical Crown of Anterior Tooth #8.

Figure 10–36. Surfaces of Clinical Crown of Posterior Tooth #30.

The clinical crown of a tooth is divided into five surfaces (figures 10–35 and 10–36):

a. *Occlusal*—the biting surface (in anterior teeth, this is termed the incisal surface).

b. *Facial*—the surface contacted by the lip or cheek.

c. *Lingual*—the surface in apposition to or contacted by the tongue.

d. *Mesial*—the surface or interproximal area facing the anterior midpoint of the dental arch at the median sagittal plane.

e. *Distal*—the interproximal surface facing away from the anterior midpoint of the dental arch.

For example: The mesial surfaces of the central incisors contact each other interproximately; their distal surfaces are in contact with lateral incisors (figure 10–37).

Restoration of tooth structures destroyed by caries or removed for prosthetic purposes are described by the surfaces which are involved and the type of material employed in the restoration. The three most common filling materials are:

(1) *Amalgam*—a silver to black colored alloy of mercury and silver.

(2) *Gold*—in the form of cast inlays and crowns, and gold foil which is malleted into cavity preparations.

(3) *Nonmetallic Materials.*

(a) Silicate—a tooth-colored silicate cement.

(b) Porcelain—a tooth-colored fired ceramic.

(c) Plastic—a tooth-colored polymer.

Destroyed tooth structure may be partially or completely replaced with a gold or porcelain crown or jacket. Restorations involving relatively large areas require gold inlays or partial crowns. These sometimes are utilized as retainers in fixed (cemented) bridges containing porcelain or resin artificial teeth.

Missing teeth are replaced by full dentures, partial dentures, or fixed bridges. The materials most commonly employed are:

1. Resin (*e.g.* acrylic)—the tissue-colored base material which forms the bulk of the appliance and supports the artificial teeth.

2. Metals:

a. Gold.

b. Chrome-cobalt alloys (chrome-colored).

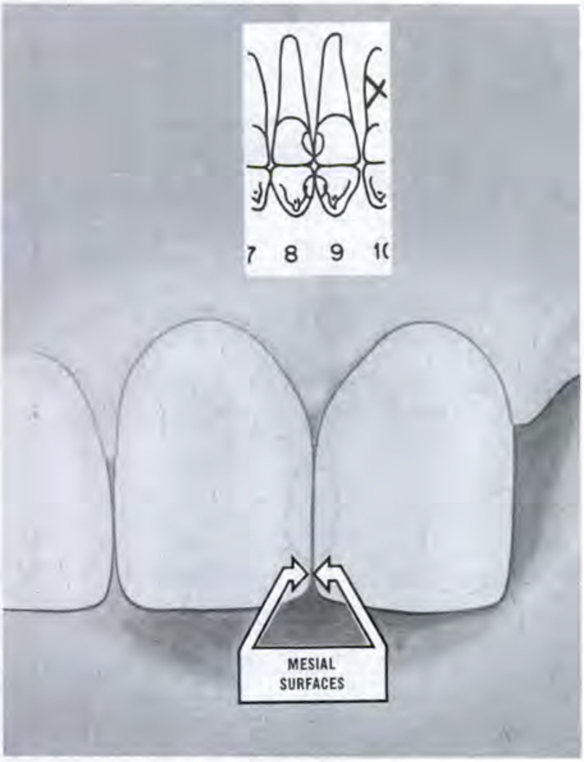


Figure 10-37. Anterior Teeth #8 and #9 in Mesial Contact at Midline of the Mouth.

These may provide the framework, base material, clasps, and support for the artificial teeth.

THE POST MORTEM DENTAL EXAMINATION

Armamentarium

Adequate illumination in the form of a supplementary light source is essential. A suitable mouth prop will be required to open the jaws for an adequate view of all tooth surfaces. The equipment should include tongue blades, 4" by 4" gauze to remove debris frequently found in the mouth and on the teeth, a mouth mirror, and rubber gloves.

Procedure

a. Force mouth open.

b. Remove debris and wipe the teeth.

c. Check for major appliances: full dentures, partial dentures, and bridges.

d. Note missing or grossly malposed natural teeth; count and numerically locate the teeth.

e. Starting in the area of tooth number one (#1), inspect and chart each restoration, noting the surfaces involved and the material employed; use SF 603.

THE DENTAL RECORD

SF 603 is accomplished (or referred to when finished) during the post mortem examination. The following symbols are employed:

Missing Teeth

An "X" is inscribed on the root of the missing tooth. Edentulous arches are designated by one large "X" or two crossing lines, each running from the uppermost aspect of one third molar to the lowermost aspect of the third molar on the opposite side.

Prosthetic Appliances

Full denture. Having designated that the arch is edentulous, indicate whether maxillary or mandibular or both, in the "Remarks" section, and describe should the denture contain areas which are other than tissue-colored resin. The palate of the denture can be of clear, transparent plastic, or this or other areas may be constructed of gold or chrome-cobalt alloy. The artificial teeth of the denture can contain fillings in the anterior region which were placed for esthetic reasons. The notation of these variations is valuable for purposes of positive identification.

Partial denture. Draw a horizontal line directly above the numerals designating teeth replaced by the partial. The "Remarks" section should indicate whether maxillary or mandibular or both and the materials employed. List the teeth which contain clasps and note the existence of palatal bars or lingual bars, which are employed to connect sections of the appliance (figure 10-40).

Silver Amalgam Restorations

Outline the filling as accurately as possible so as to indicate the shape and extent of the restoration. Block in solidly (figure 10-41).

Note (in inset) that the molars and bicus-

Standard Form 603
Rev. November 1953
Bureau of the Budget
Circular A-32 (Rev.)

HEALTH RECORD | **DENTAL**

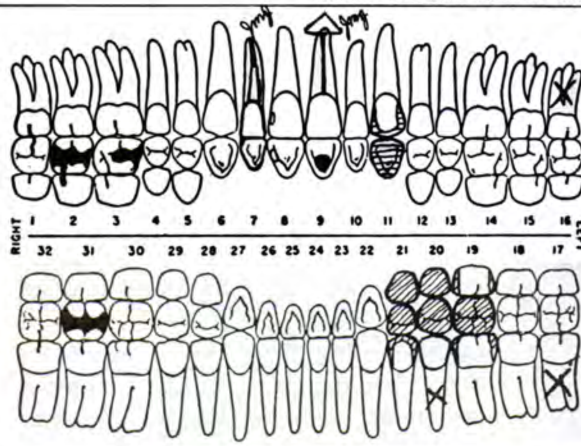
SECTION I. DENTAL EXAMINATION

1. PURPOSE OF EXAMINATION: [X] INITIAL [ ] SEPARATION [ ] OTHER (*Specify*)

2. TYPE OF EXAM.: [X] 1 [ ] 2 [ ] 3 [ ] 4

3. DENTAL CLASSIFICATION: [ ] 1 [ ] 2 [X] 3 [ ] 4 [ ] 5

4. MISSING TEETH AND EXISTING RESTORATIONS



REMARKS

Teeth # 7, 10 in slight labioversion.

Harelip, incomplete, left lateral, repaired.

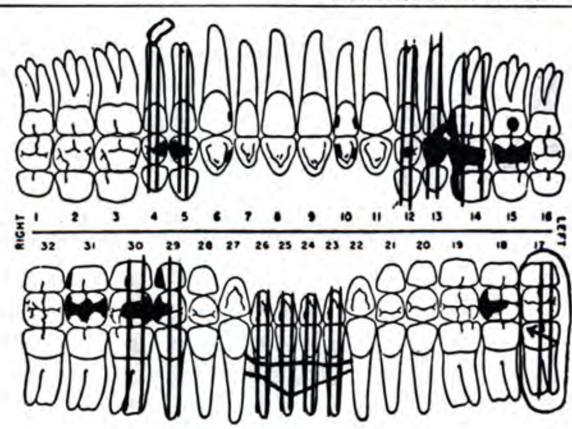
History of mandibular fracture, (1944) midline, healed.

PLACE OF EXAMINATION: - - - - - - - - AFB, Tex.

DATE: 1 Jul 65

SIGNATURE OF DENTIST COMPLETING THIS SECTION: Thomas E. Brewer, Capt. USAF, DC

5. DISEASES, ABNORMALITIES, AND X-RAYS



A. CALCULUS: [ ] SLIGHT [ ] MODERATE [X] HEAVY

B. PERIODONTOCLASIA: [X] LOCAL [ ] GENERAL; [ ] INCIPIENT [ ] MODERATE [X] SEVERE

C. STOMATITIS (*Specify*): [X] GINGIVITIS [ ] VINCENT'S

D. DENTURES NEEDED (*Include dentures needed after indicated extractions*): FULL [ ] U [ ] L; PARTIAL [X] U [X] L

ABNORMALITIES OF OCCLUSION—REMARKS

Tooth #12 rotated 25 degrees mesially.

Def Fx Pr Dtr #19, 20, 21.

Car under fil #31.

E. INDICATE X-RAYS USED IN THIS EXAMINATION: [X] FULL MOUTH PERIAPICAL [X] POSTERIOR BITE-WINGS [ ] OTHER (*Specify*)

DATE: 1 Jul 65

PLACE OF EXAMINATION: - - - - - - - - - - - - - - - - -AFB, Tex.

SIGNATURE OF DENTIST COMPLETING THIS SECTION: John M. Jones, LtCol, USAF, DC

SECTION II. PATIENT DATA

6. SEX	7. RACE	8. GRADE, RATING, OR POSITION	9. ORGANIZATION UNIT	10. COMPONENT OR BRANCH	11. SERVICE, DEPT., OR AGENCY
M	Cau	TSgt	3792 AB Gp	Reg	AF

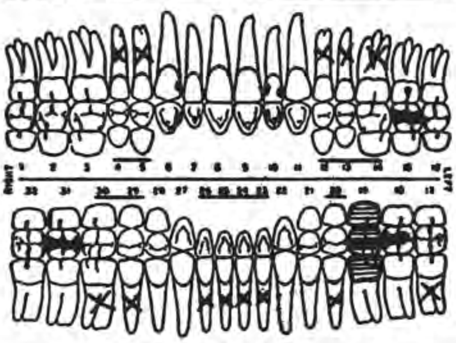
12. PATIENT'S LAST NAME—FIRST NAME—MIDDLE NAME	13. DATE OF BIRTH (DAY—MONTH—YEAR)	14. IDENTIFICATION NO.
Dobbs, Joseph Albert	27 May 24	AF 204 107 17

DENTAL
Standard Form 603
603-102

Figure 10-38. SF 603, "Dental Health Record, Sections I and II."

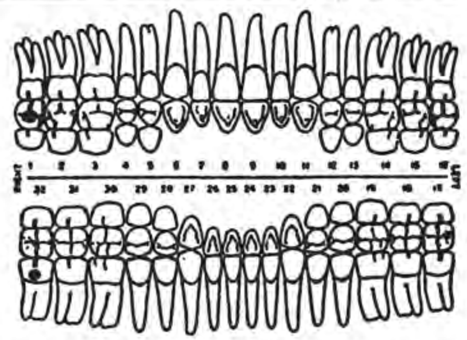
SECTION III. ATTENDANCE RECORD

15. RESTORATIONS AND TREATMENTS *(Completed during service)*



REMARKS

16. SUBSEQUENT DISEASES AND ABNORMALITIES



REMARKS 20 May 66 - Car #1, #32 - JMS

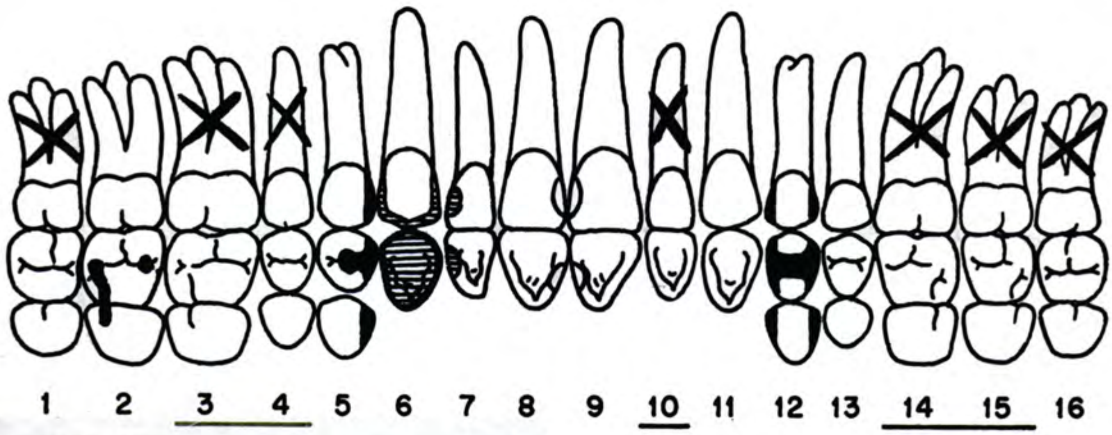
17. SERVICES RENDERED

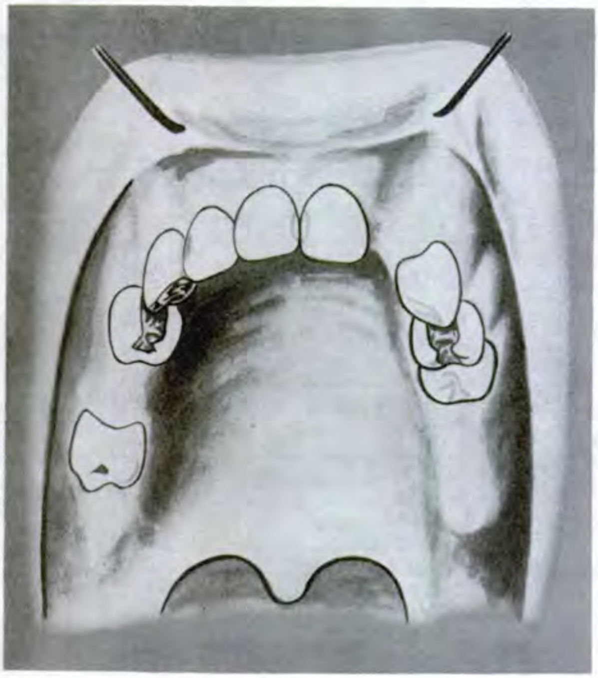
DATE	DIAGNOSIS—TREATMENT	CLASS	OPERATOR AND DENTAL FACILITY	INITIALS
			- - - - - - - - AF Base	
15Jul65	Cal heavy Pro. Poor oral hygiene noted.			
	Prev Dent Counseling.	3	S.M.Hayes	SMH
22Jul65	SF 513,Consultation Report from Int Med			
	Sv enclosed (Anes allergy negative).	3	R.S.Miles	RSM
29Jul65	Pulpitis #5,29,30;Abs per #4 chronic			
	Ext AnesGen 30Jul POT	3	R.S.Miles	RSM
5Aug65	Pulpitis #12,13,14; Tooth Imp #17 Ext			
	AnesGen 6Aug POT 9Aug POT 11Aug POT	3	R.S.Miles	RSM
10Aug65	SF 515,Pathology Report enclosed(neg.)	3	R.S.Miles	RSM
1Sep65	Car #6-M, #10-M, #10-D S11	3	M.R.Stone	MRS
6Sep65	Car #15-MOD B Am, #15-F Am, #18-MO B Am	3	M.R.Stone	MRS
13Sep65	Def Fil #31-MODL B Am AnesReg	3	M.R.Stone	MRS
17Sep65	Def Fx Pr Dtr Man Removed;Cr #21 Recem	4	W.T.Wright	WTW
8Oct65	Pedono severe #23,24,25,26 Ext AnesReg	4	R.S.Miles	RSM
11Oct65	Re,Pedono POT	4	R.S.Miles	RSM
20Oct65	Pedono moderate #2,3,18,19 Gtmy AnesReg	4	A.M.Green	AMG
27Oct65	Re,Pedono POT Pack removed.	4	A.M.Green	AMG
19Nov65	PrepImpr #19 AnesReg	4	W.T.Wright	WTW
29Nov65	Car #19-Full Cr Gold	4	W.T.Wright	WTW
3Dec65	ImprMaxMan	4	E.L.Davis	ELD
13Dec65	Missing Teeth #4,5,12,13,14,20,23,24,25,			
	26,29,30 Rem Dtr Pr Max Ticonium Acr			
	Rem Dtr Pr Man Ticonium Acr 22Dec DtrAdj	1	E.L.Davis	ELD
			- - - - - - - - AF Base	
20May66	Exam Type 2 SF 88	2	J.M.Stewart	JMS

PATIENT'S LAST NAME—FIRST NAME—MIDDLE NAME: Dobbs, Joseph Albert

U.S. GOVERNMENT PRINTING OFFICE : 1962 O—664314

Figure 10-39. SF 603, "Dental Health Record, Section III."





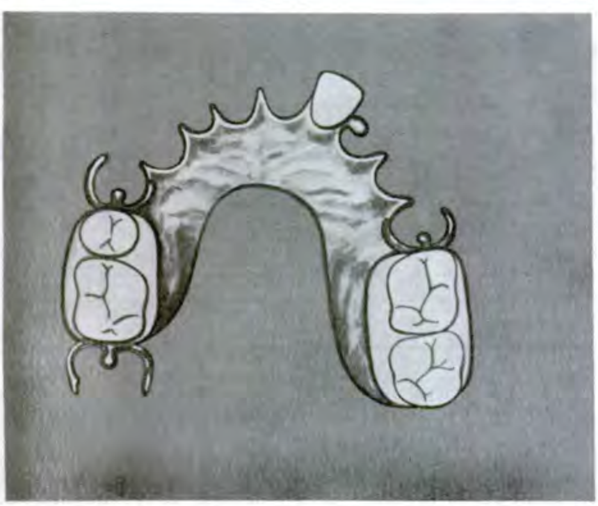


Figure 10–40. An Upper Partial Denture Replacing Teeth #3, 4, 10, 14, and 15, and Method for Graphic Indication.

pids are illustrated in three aspects. The upper is the facial, the middle is the occlusal and the lower, the lingual aspect of these teeth. Thus, the restorations may be drawn accurately so as to indicate the exact extension and areas of the tooth involved by the restoration. Insufficient area on the incisal edge of the centrals, laterals, and cuspids precludes drawing the involvement of this region.

Gold Restorations

Outline as described above and inscribe a series of parallel lines within the area of the restoration as follows:

a. Individual restorations—the parallel lines are horizontal (figure 10–42).

b. When inlays or crowns are parts of fixed partial dentures (bridges), the parallel lines are diagonal (figure 10–43).

Nonmetallic Restorations

Fillings, crowns, and bridge facings (usually supported by gold) are outlined so as to indicate size, shape, and location.

Special Entries for Identification

Record under "Remarks" findings such as eroded areas, mottled enamel, Hutchinson's teeth, rotation, irregularity of alignment, presence of supernumerary teeth, irregular

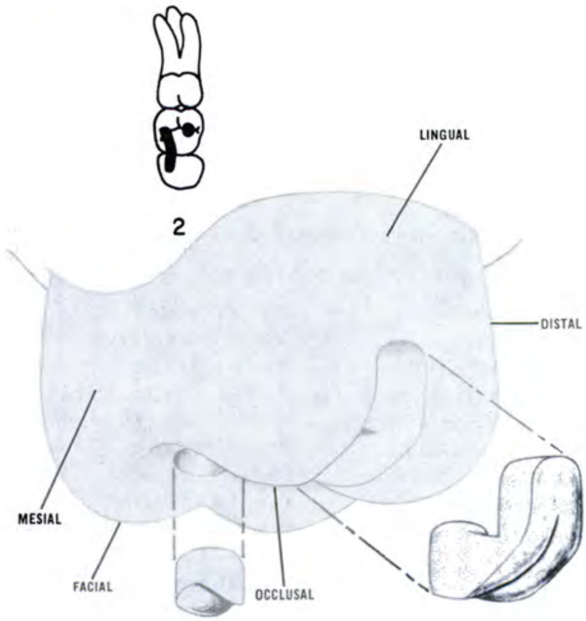


Figure 10-41. Two Amalgam Restorations in Upper Right Second Molar Indicating Surface Involvement.

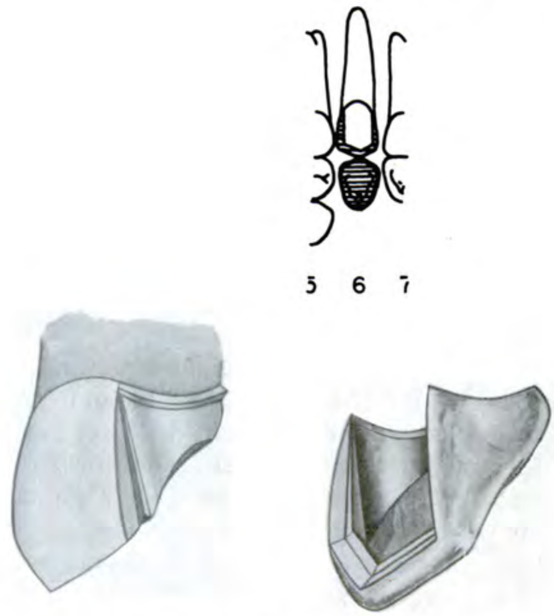


Figure 10-42. A Three-quarter Cast Gold Crown on the Upper Right Cuspid.

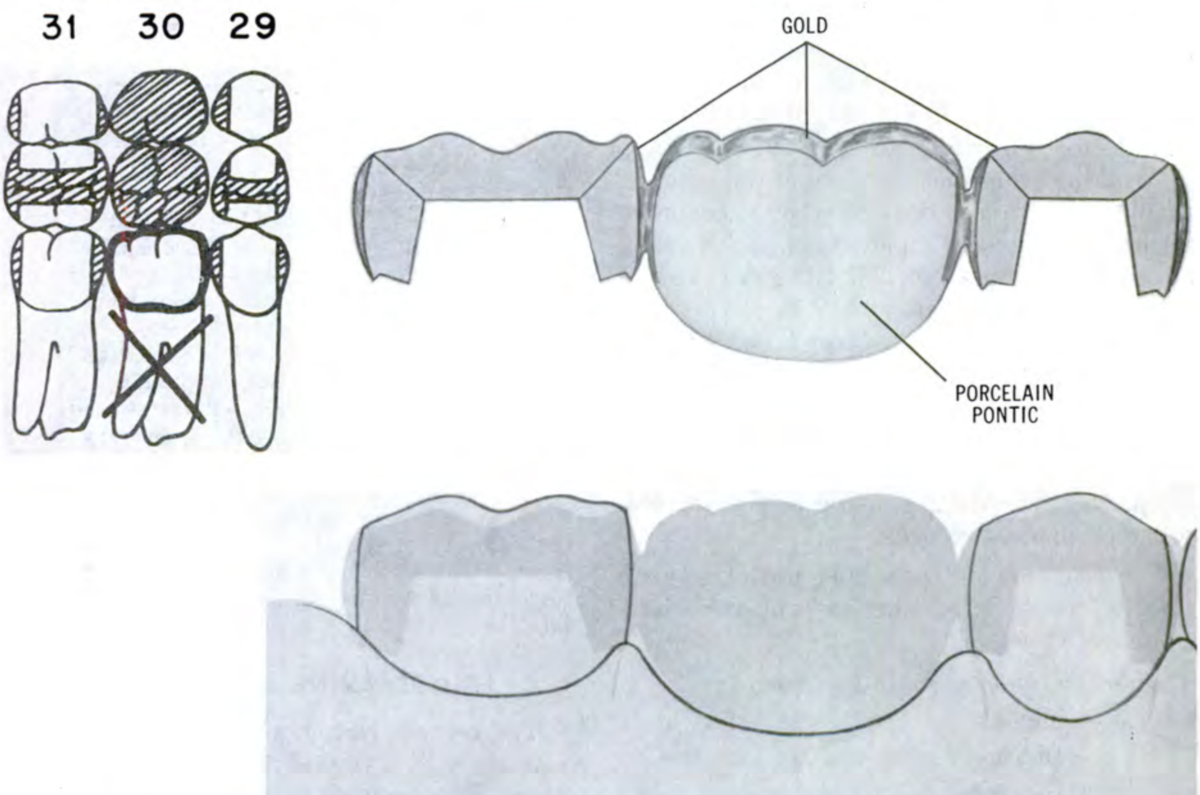


Figure 10-43. A Fixed (Cemented) Bridge Replacing Lower Right First Molar by Means of Inlays on the Second Biscuspid and Second Molar.

bone development (torus palatinus or mandibularis), and unusual restorations or appliances. These entries are important for diagnostic or identification purposes.

When SF 603 is provided as a completed record for identification prior to the post mortem dental examination, the physician must be able to interpret the symbols thereon in order to correlate them with the examination of the oral cavity. Item 4, "Missing Teeth and Existing Restorations," and item 15, "Restorations and Treatments (completed during service)," are both referred to for the current recorded condition of the mouth. On SF 603, items 4, 5, 15, and 16 apply.

ACCOMPLISHMENT OF DENTAL TREATMENT RECORDS

SF 603 under custody of the Air Force, provides the basic permanent Air Force record of a person's dental health. The physician may be called upon to record emergency dental attendance in the absence of a dental officer. These forms are to be used when dental care is provided any person. Authentic information contained in temporary records should be transcribed to the permanent records by qualified personnel. Such temporary records may include SF 603 (used as transitory materials) and AF Form 644, "Record of Dental Attendance" (white) for Air Force personnel, AF Form 644a (green) for Army Personnel, Navy-Marine, Dependents, and all others. Consultant reports and the laboratory reports are considered temporary records and should be transcribed to the permanent records.

For economy of space and uniformity of records, abbreviated entries are authorized as indicated below:

Abbreviations for tooth surfaces:

M — Mesial
I — Incisal
O — Occlusal
D — Distal
F — Facial
L — Lingual

Combinations. When more than one tooth is involved, a combination of the abbreviating capital letters is employed. *Examples:* MO, mesio-occlusal; DO, disto-occlusal; MOD, mesio-occlusal-distal; DOF, disto-occluso-facial. #9-MID, maxillary left central incisor, mesio-inciso-distal surfaces.

Other authorized abbreviations:

Abr — Abrasion
Abs — Abscess
Acr — Acrylic
Adj — Adjust (ed, ment)
Alvy — Alveolectomy
Am — Amalgam
AnesReg — Anesthesia, regional
AnesGen — Anesthesia, general
Apcy — Apicoectomy
B — Base
BrFx — Bridge fixed
Car — Caries
Cal — Calculus
Cem — Cement
Cr — Crown
Cstmy — Cystectomy
Dec — Deciduous
Def — Defective
Dtr — Denture
Drn — Drain
Drs — Dressing
Equil — Equilibrate (ation)
Eug — Eugenol
Exam — Examination
Ext — Extraction (Tooth Removal)
Fil — Filling (s)
Fl — Fluorine
Frac — Fracture (s)
Gen — General
Ging — Gingival (itis)
Gtmy — Gingivectomy
GP — Gutta percha
Imp — Impacted (tion)
Impr — Impression
Inc — Incised
Inl — Inlay
Ins — Inserted
Max — Maxillary
Man — Mandibular
Pecor — Pericoronitis
Pedon — Periodontoclasia
Pr — Partial
Par — Parietal
Per — Periapical
Porc — Porcelain
POT — Postoperative treatment
Prep — Prepared (ation)
Pro — Prophylaxis
Reapt — Reappoint (ment)
Re-Exam — Re-examination
Recem — Recement (ed)
Rct — Reconstruct (ed)
Re — Reference
Red — Reduce
Reg — Regional
Rel — Reline
Rem — Removal (ed)
Rpd — Repaired
RC — Root canal
Sed — Sedative (ation)
Seq — Sequestrum
Sil — Silicate
Stom — Stomatitis
Surg — Surgical
Su — Suture (s) (d)
Tem — Temporary
Tr — Treatment
Uner — Unerupted
Vin — Vincent's
XR — X-ray
ZnCl — Zinc chloride
ZnO — Zinc oxide

FIELD PERSONNEL RECORDS GROUP

The records include certain dental records identified as "Dental Treatment Records." They are contained in DD Form 722-1, "Dental Folder—Health Record," or in manila envelopes marked "Dental Treatment Records." The base or unit dental surgeon is normally custodian. Emergency dental treatment records are to be made available to the dental custodian requesting them. At bases with a high rate of turnover, or in certain other local circumstances the dental treatment records remain in the Field Personnel Records Group files. The records for emergency cases may be withdrawn as required.

The physician is responsible for caring for and properly administering the dental treatment records while in his temporary custody. When advised of the movement of the Field Personnel Records Group, the physician should forward the records of emergency treatment to the base or unit custodian. If necessary during movement of personnel, temporary dental treatment records may be established pending the arrival of the Records Group.

The importance of maintaining current dental records, especially for those individuals on flying status and those who otherwise may be required to fly, cannot be overemphasized.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Aerospace Medicine,* Chapter 24, "Aviation Dentistry." The Williams and Wilkins Company, Baltimore, 1961.

Szmyd, L., *Oral Surgery Complications Caused by Flight.* US Armed Forces Medical Journal 9:264–270, 1957.

Szmyd, L., *Air Evacuation of Maxillofacial Injuries.* Archives of Surgery, 74:809–813, 1957.

Emergency Oral Medicine. School of Aviation Medicine, USAF, Randolph Air Force Base, Texas, 1957.

Accepted Dental Remedies (published annually by the American Dental Association).

AFM 162–1, *Dental Administrative and Technical Procedures.*

Chapter 11

DRUGS AND THE FLIER

There are few, if any, drugs which are not of importance in relation to flying duty, and particularly to a pilot. The use of drugs by flying personnel usually becomes a problem when adequate medical administrative control is not exercised by the Flight Surgeon or when airmen have not received adequate medical indoctrination. It is the Flight Surgeon's responsibility to take the necessary steps to see that no one flies as an aircrew member while under medication which might impair flying efficiency.

The Flight Surgeon must keep well informed on all drugs, particularly newly accepted ones, so that no medication will be prescribed which might compromise flying safety. Individual susceptibility to drugs in general must always be considered. The Flight Surgeon is responsible for the proper medical indoctrination of airmen with respect to drugs. He must continuously see to it that his airmen perform flying duty only when in good physical condition and under no adverse influences. He must make them realize the dangers of using certain drugs when flying and the danger of self-medication.

When new drugs receive popular acclaim in various periodicals, it becomes necessary for the Flight Surgeon to see that the flying personnel are thoroughly indoctrinated regarding, these drugs. This is particularly true of new medications containing depressants, some of the more powerful analeptics, the antihistamines, the atropine-like compounds, and other drugs affecting the psychomotor and sensory functions.

Among drugs used in self-medication, antihistaminics may be particularly dangerous if used indiscriminately. A marked individual response is shown to antihistaminics, varying from no effect in some persons to drowsiness, and even severe depression, in others. These drugs depress the vestibular apparatus and decrease depth perception, thus creating a great hazard to personnel attempting to fly while using them.

Nasal decongestants should also be administered carefully. Due to the marked absorptive power of the nasal mucosa, tachycardia and nervous states, including tremors and incoordination may occur if nasal decongestants are used indiscriminately. Mydriasis may also be caused by these drugs, and again a hazardous situation is present. Care must be exercised in the use of certain drugs for prophylactic purposes, which may be considered harmless in smaller dosages.

Prophylactic drugs, such as some of the antimalarials, frequently cause visual difficulties. Quinine and other drugs of the cinchona group given in relatively small doses, frequently cause tinnitus and deafness, the latter being an individual response to the drug. The use of atropine-like substances, such as hyoscine, which is frequently found in preparations used to treat the common cold and is also the main ingredient of some airsickness pills, and antispasmodics, used in ulcer symptoms, will cause sufficient mydriasis and cycloplegia to be dangerous.

The use of chloroquine-primaquine has been approved for malaria prophylaxis in flying personnel who are operating in endemic malaria areas. Although the possibility of adverse reactions is slight with recommended prophylaxis doses, the Flight Surgeon should be fully cognizant of the potential undesirable effects. Pretesting of crewmembers has been recommended.

One of the most important groups of drugs in medicine is the antibiotic group. There is frequently a tendency to use them indiscriminately. Of these, two may be very dangerous to flying personnel—namely, streptomycin and dihydrostreptomycin. Both of these drugs may cause permanent hearing and vestibular damage, but dihydrostreptomycin does not give a warning of dizziness as does streptomycin. It is strongly recommended that neither of these drugs be given to flying personnel when another drug will do the job. If used, as for example against H. Influenzae, thorough hearing and vestibular testing should be done before starting therapy and weekly during the therapy. The therapy should be stopped immediately if any decrease in function occurs, unless the drug is necessary to save life.

Chloramphenicol has been shown to have an adverse effect on the hemopoietic system. It may occasionally cause aplastic anemia. Because of this action on the hemopoietic system, it may decrease the oxygen transport, and thus its use in flying personnel should be carefully controlled.

Various other drugs tend to decrease tolerance to hypoxia. Carbonated alkalizers taken in large amounts or too frequently, tend to cause the formation of methemoglobin, as do acetanilid and phenacetin.

Special consideration must also be given certain drugs which may be used in air evacuation. Since more and more battle casualties and other patients are being transported by air, it becomes necessary for the Flight Surgeon to evaluate the use of drugs in flight which would not ordinarily be used by him on flying personnel. For analgesia during flight, it is fairly obvious that morphine, due to its respiratory depression, should be very carefully controlled, if used at all.

The synthetic drugs, such as meperidine, have less effect on respiration. For sedation, the barbiturates should not be used in too large doses, since they may cause a stage of anesthesia deep enough to depress the respiratory center. Chloral hydrate is not advocated, since both respiratory and cardiac depressions are associated with its use. Of the sedatives, paraldehyde is probably the best, causing no depression of either respiration or heart function.

The factors which most frequently modify the action of drugs in flight are *hypoxia* and *fatigue*. A brief discussion follows on drugs in these categories.

Drugs Which Increase Tolerance to Hypoxia

Drugs which increase the partial pressure of oxygen in alveolar air, diminish the oxygen requirement of the organism, or act as respiratory stimulants, may increase tolerance to hypoxia. Such drugs are ammonium chloride, glucose, and analeptics.

Ammonium Chloride

It has been demonstrated that 10 to 20 gm of ammonium chloride a day for 3 days will increase the arterial oxygen saturation about 10% at 18,000 feet. This results in improved performance and a smaller acceleration of the pulse than expected. The probable mechanism of action is explained by an increase in the exhalation of carbon dioxide with a resulting increase in alveolar oxygen tension. It may be due to a slight shift in the acid-base balance with a resulting change in oxyhemoglobin formation and dissociation. Unfortunately, such doses of ammonium chloride often produce gastrointestinal irritation.

Glucose

Visual and psychomotor tests in humans suggest that the ingestion of glucose improves performance at altitude. There is some evidence that a low blood sugar interferes with oxygenation of the central nervous system so that a mild lack of oxygen may produce symptoms which would not occur with normal blood sugar. The higher alveolar respiratory quotient on a carbohydrate diet also plays a role in decreasing the alveolar carbon dioxide tension. These facts would seem to justify the ingestion of foods rich in carbohydrate, immediately before a high-altitude mission.

Analeptics

Under conditions of hypoxia, amphetamine 10 mg, methamphetamine 5 mg, dextroamphetamine 5 mg, or caffeine sodium benzoate 500 mg improve psychomotor performance. There is some evidence that amphetamine is superior to caffeine for this purpose. However, a great deal of evidence shows that amphetamine or dextroamphetamine in therapeutic doses may adversely affect one's judgment. Every precaution should be used when it is administered to flying personnel.

Drugs Alleged to Reduce Tolerance to Hypoxia

If the administration of sulfonamides results in an anemia or methemoglobinemia, or if the subject is abnormally susceptible, there is no doubt that tolerance to hypoxia is reduced. Otherwise, there is evidence that, of the sulfonamides, only sulfanilamide in moderate doses diminishes tolerance to hypoxia. From experiments at sea level, there is evidence that sulfanilamide should not be used when doing exacting or strenuous work. Depth perception and phorias may be adversely affected by sulfathiazole or sulfadiazine.

There seems to be no significant effect on staring and vigilance, dark adaptation, mental efficiency, or eye-hand coordination. There are also no effects on various intellectual and psychomotor functions under hypoxic conditions, or the ability to perform exhausting work. The occasional abnormal toxic response to the sulfonamides may be aggravated by conditions of flight and may be more dangerous because of the exacting demands of the situation.

Drugs for Airsickness

Most airsickness drugs fall into three categories—parasympathetic depressants, central nervous system depressants, or antihistaminics. Drugs that are effective against one type of motion sickness are, generally though not necessarily, effective against the other types as well. As far as can be determined, there is good correlation between drugs and their effectiveness against the sickness produced by various types of motion. To be useful in flying personnel, a drug should diminish the incidence of airsickness; not impair the capacity to perform duties; and not be toxic, habit-forming, or cause disagreeable symptoms. Also, it should be active in a reasonably short time after oral administration.

Depression of the central nervous system renders the barbiturates of doubtful value for flying personnel. In fact, in experiments on the swing and in seasickness, they have not been shown to be particularly effective nor have they appeared to contribute to the beneficial effects of other drugs when used for motion sickness. Those studied include phenobarbital, barbital, amobarbital, and pentobarbital. However, the Army motion sickness preventive, containing sodium amobarbital, hyoscine, and atropine, is effective in swing sickness, seasickness, and airsickness. Whether this is due entirely to its content of hyoscine and atropine has not been demonstrated.

Of the numerous compounds and mixtures tested, those of the atropine series have shown the most substantial protection against airsickness. Because of the high degree of protection and low incidence of side effects, scopolamine has been the most widely used of the antimotion sickness drugs.

In 1949, the report of Gay and Carliner on the effectiveness of dimenhydrinate in seasickness stimulated considerable interest in the use of antihistamines for motion sickness. Yet, subsequent tests showed scopolamine to be still more effective than either dimenhydrinate or diphenhydramine HCl. Since the pharmacological properties of diphenhydramine HCl and scopolamine are not identical, however, a mixture of these two drugs was tested. Hyoscine hydrobromide (0.65 mg) was mixed with diphenhydramine HCl (50 mg). Greater protection was shown with the mixture than with scopolamine alone. A preparation containing half of these components was tested and found to be as effective as the full dose of hyoscine alone, with fewer side effects. Good protection has been afforded by the following preparations, in addition to those already mentioned: Promethazine HCl, chlorpheniramine, cyclizine, and meclizine HCl.

The School of Aerospace Medicine has carried out a very extensive program of testing the various drugs for their effectiveness in controlling motion sickness. Statistically, there is little difference in the effectiveness of the conventional drugs, such as cyclizine, dimenhydrinate, meclizine HCl, and promethazine HCl. The actual choice of drugs to be used is dependent almost entirely upon individual differences in the response of the patient to the drugs.

None of the drugs mentioned above has been demonstrated to be safe for use by aircrew members. However, on occasion, they may be used in the early training period of cadets and officers training in grade, provided the student is not in primary control of the aircraft. The use of these drugs, therefore, will be limited to dual instruction periods and will be carefully controlled by the Flight Surgeon. Extreme care must be taken with regard to preliminary testing to avoid unusual reactions which may occur as a result of hypersensitivity of a person. In addition, the instructor pilot must be properly notified and indoctrinated concerning the use of the airsickness preventive by the student.

The use of the drugs should never be prolonged but should be limited to a relatively short training period, as a means of supporting the person during a period of 3 or 4 weeks when he is developing a resistance to the effects of motion. The Flight Surgeon must take particular care in assuring that proper control of the use of these drugs is enforced and that unauthorized use of them by the student is prevented.

Drugs for Fatigue

Men can postpone sleep and fatigue and remain alert to carry on their duties for many hours longer than they would normally if they receive dextroamphetamine at appropriate intervals. This drug is not habit-forming in the sense that physical signs of withdrawal are produced. However, many find the stimulation pleasant, and excessive use may occur. Overdosage will produce excessive excitement, headache, and sleeplessness. Some people are unusually susceptible to the actions of this drug. It is no substitute for rest or sleep, but merely postpones the need for it.

If a drug of this nature is felt to be necessary for mission completion, then it is an admission that the flight exceeds the capability of the fliers. Accordingly, mission replanning is indicated rather than reliance on medication which may have unpredictable results.

AIR FORCE POLICY

The Surgeon General, United States Air Force, does not interfere with the privilege each physician has to practice good medicine. With particular reference to drugs, there has been practically no dictation to the practitioner as to what drugs will or will not be used. However, it has been and is now Air Force policy that, *in general,* no drugs will be used by an individual while on flying status.

Flight Surgeons must be especially alert to detect self-medication and must take steps to insure that drugs are not being given to flying personnel either through self-medication or by allied medical service personnel who are not Flight Surgeons. The Flight Surgeon can do much to control the latter through the establishment of adequate rapport and liaison with other medical service personnel, such as ward officers and dentists, so that the Flight Surgeon is informed when flying personnel are being treated by them.

The use of antihypertensives, anticholinergics, antihistaminics, tranquilizers, and sedatives is fraught with *considerable* risk and their use by personnel on flying duty is contraindicated. The indications for the use of these and other drugs in general are sufficient cause in themselves for removal from flying status.

DRUG USE AND ABUSE

A number of foreign countries do not have limitations as strict as those of the United States on the type of drugs that can be purchased "over the counter" without a prescription. Prolonged or frequent use of certain items available under foreign laws can cause personal harm and create disciplinary problems. Some of the preparations, which are sold under various brand names, are barbiturates and amphetamines. The dangers from the indiscriminate, unprescribed use of these preparations by flying personnel are self-evident.

Although surveys and investigations have disclosed few instances of such drug use and abuse, Flight Surgeons and Commanders must be continuously alert to the possible existence of this problem, particularly in oversea areas. Personnel should be warned of the hazards associated with the purchase and use of drugs from the local market, pointing out that these preparations may contain substances which, under US law and medical practice, are considered harmful and undesirable except when used under the close direction of their physician.

REFERENCES

The reader should insure the currency of listed references.

Ashe, W. F., *Drugs: Are They Friend or Foe of the Aviator?* Proceedings of Aviation Medicine Symposium on Toxic Hazards in Military Flying and in the Aviation Industry, Headquarters Air Materiel Command, 1957.

Armstrong, H. G., *Aerospace Medicine*, Chapter 26, "Aircrew Maintenance," The Williams and Wilkins Company, Baltimore, 1961.

Cutting, W. C., *Guide to Drug Hazards in Aviation Medicine*, Federal Aviation Agency, Aviation Medical Service, 1962.

Effects of Chloroquine on the Speed of Visual Accommodation in Man. USAF School of Aviation Medicine Project No. 21 1601-005, 1953.

Gay, L. N., and Carliner, P. E., *The Prevention and Treatment of Motion Sickness: I. Seasickness.* Science, 109:359, 1949.

Glorig, A., *The Effect of Dihydrostreptomycin Hydrochloride and Sulfate on the Auditory Mechanism.* Annals of Otology, Rhinology and Laryngology 60:327-335 (1951).

Greenwood, G. J., *Neomycin Ototoxicity.* Archives of Otolaryngology 69:390-397 (1959).

Haas, W. R., *Anti-Malarial Drugs in Flying Personnel,* Journal of Aviation Medicine. February 1955.

Leake, C. D., *The Amphetamines and the Sleepy Driver.* Ohio Medical Journal 176-178, 1957.

Lett, J. E., *Nasal Vasoconstriction in Flying.* USAF, Medical Service Digest, Volume III, No. 5, July 1952.

Naunton, R. F., and Ward, P. H., *Ototoxicity of Kanamycin Sulfate in the Presence of Compromised Renal Function.* Archives of Otolaryngology 69:398-399 (1959).

Smith, G. M., and Beecher, H. K., *Amphetamine, Secobarbital, and Athletic Performance: II. Subjective Evaluations of Performances, Mood States and Physical States.* Journal of American Medical Association 172:1502-1514, 2 April 1960.

Smith, G. M., and Beecher, H. K., *Amphetamines, Secobarbital, and Athletic Performance: III. Quantitative Effects on Judgment.* Journal of American Medical Association 172:1623-1633, 9 April 1960.

Shambaugh, G. E., Jr., *et al., Dihydrostreptomycin Deafness.* Journal of American Medical Association 170:1657-1660 (1959).

Waters, R. O., *Ototoxic Drugs.* USAF Aerospace Medical Center, School of Aviation Medicine Review 5-60, October 1960.

Wittmer, J. F., *Aeromedical Aspects of Malaria Prophylaxis with Chloroquine-Primaquine,* Aerospace Medicine, October 1963.

Chapter 12

FATIGUE IN AEROSPACE OPERATIONS

The achievement of global strategic and tactical capability has magnified many professional problems for the Flight Surgeon, but perhaps none more than the problem of aerospace crew fatigue. The perfection of in-flight refueling techniques and the extension of aircraft range through better design and engineering have resulted in vastly more prolonged operations than those encountered in the past. The Flight Surgeon of today finds himself confronted with fatigue problems from every conceivable operational source, whether it be prolonged B-52 flights, oversea tactical deployment of fighter aircraft, around-the-clock troop carrier and MAC support of far-flung operations, missile launch control duty or planning the daily routine of the astronaut.

The Flight Surgeon needs to be able to recognize and manage the fatigue problems which occur within his sphere of control. The Directorate of Flight and Missile Safety Research is convinced that many of the faulty decisions that contribute to aircraft accidents at the end of long missions can be ascribed to fatigue. An equally critical consideration is the fact that fatigue-induced performance decrements might cripple a mission on which the safety of our nation may depend. Such considerations make it obligatory to review the general subject of fatigue to assist the Flight Surgeon toward a better understanding of its etiology, prevention and control.

RESEARCH ON THE PROBLEM

There has been no lack of conscientious inquiry into the problem of fatigue in aerospace operations. The almost endless number of fatigue-producing factors present in man and his environment, and the number of these factors which cannot be simulated in the laboratory have made this area of research one amply endowed with frustration. Nevertheless, we have gained considerable insight into a number of facets of the problem. A thorough, critical review of the research efforts in this area is beyond the scope of this chapter, but one will be well repaid if he scans some of the references listed at the end of this chapter. From the early work of F. C. Bartlett in 1942 with the "Cambridge Cockpit" up through the latest review of fatigue by O. B. Schreuder in 1966, many investigators have added to our knowledge of what fatigue is, when one should suspect its presence, how one recognizes it, and what one can do about it. Unfortunately, none of the studies, including the biochemical determinations of various "stress catabolites," are able to give us a reliable answer to our basic question: "When is a crew member too fatigued to fly safely and proficiently?" Before reviewing some of the studies listed at the end of this chapter, one should be forewarned that, at present, there are no practical and objective tests to answer the key question asked above.

The present treatment of the subject of fatigue will be disappointingly vague because the size and complexity of the problem far exceed the available knowledge. However, a delineation of what little is known will serve a useful purpose, and a realization of what remains to be discovered may stimulate the careful observer to contribute significant observations from his day-to-day professional practice. A reasonable approach to the problem might well involve:

a. First, the consideration of a practical, working definition of fatigue and a description of the types of situations likely to engender significant amounts of fatigue.

b. Second, a discussion of the kinds of observations which support a diagnosis of fatigue, and an attempt to provide theoretical perspectives within which these observations can be evaluated. Finally, some of the actions available to the Flight Surgeon for the prevention and relief of fatigue will be suggested.

WHAT IS FATIGUE?

The word "fatigue" arose from the Latin *fatigare*, meaning "to waste away." Viewed in this sense, the term has enjoyed a very general descriptive usefulness by many scientific and technical disciplines to denote a change in some natural property from a stronger to a weaker manifestation. Unfortunately, these widespread applications of the word "fatigue" have resulted in many variations, both in its *specific* meaning and in the inciting causes implied by its use. To understand what is meant by "fatigue," one must know the scientific discipline of the user. To the exercise physiologist, "fatigue" implies decrements in muscle strength associated with depleted energy-producing compounds and increases in anerobic breakdown products, such as lactic acid. To the metallurgist, "fatigue" implies a progressive deterioration in the strength of a metal associated with crystalline changes in its structure as a result of repeated stresses. To the psychologist, "fatigue" may imply a mental state characterized by decreasing motivation, an elevated threshold for stimuli and a decrease in accuracy and speed in solving problems or carrying out psychomotor tasks. To the Flight Surgeon, who is more interested in the "whole man" and his capability to perform as an integrated part of a weapon system, we can best define "fatigue" as that condition characterized by a detrimental alteration or decrement in skilled performance related to duration or repetitive use of various skills. Physical, physiological, and psychological stresses may singly or in combination accentuate the fatigue state.

It is thus clear that, to determine the etiological basis of fatigue in aerospace operations, one must learn to distinguish carefully between various factors that might induce or aggravate a decrement in performance. Each instance must be regarded as having its own etiological chain, along which physical, physiological, and psychological factors may assume importance. This caution merely recognizes that behavior can deteriorate in many different ways and for many different reasons. The task of the Flight Surgeon is to discover the reasons for a particular deterioration, pursue all possible means to arrest it, and restore full performance capability. In so doing, the Flight Surgeon will often find himself dealing with factors and circumstances far removed from traditional notions of fatigue. Ideally, the Flight Surgeon will attempt to recognize those potential factors which may lead or contribute to fatigue, and prescribe the necessary corrective measures to prevent the problem.

VARIETIES OF FATIGUE

Flying fatigue is generally identified in two overlapping categories: Acute Skill Fatigue and Chronic Flying Fatigue. A third classification of physical or muscular fatigue on rare occasions, may be important in the flying environment. Generally, the physical exertions of flying are not great enough to create the muscular fatigue encountered in prolonged manual labor. However, prolonged sitting, encumbered by personal equipment of varying degrees of discomfort, may cause static muscular discomfort as a result of stasis and local pressure point hypoxia.

Acute Skill Fatigue

Acute skill fatigue or "single mission skill fatigue" is that tendency towards decrement in either quality or quantity of skilled work output which occurs concomitant with the prolonged application of oneself to a demanding task.

The etiology of this type of fatigue is primarily psychological. Monotony of the task, particularly one that requires close, continued attention and carries considerable personal responsibility for the consequences of any lapses in attention, is an important cause. Apprehension, boredom, relative immobility, and *lack* of apparent threat to life or limb all contribute to a progressive disinclination to observe and critically evaluate what is going on around the operator. As would be expected, physiological factors such as mild hypoxia, hypoglycemia, dehydration, and recent illnesses all can contribute to a lessened ability of the operator to resist the psychological factors. Environmental factors such as weather and turbulence, high noise levels in the cockpit or in the headphones, and discomfort from inadequate cockpit temperature controls will further lessen the operator's resistance to the stultifying psychological factors.

Symptoms and signs of acute skill fatigue fall into three general areas:

a. *Decrement in psychomotor functions* manifested by decreased coordination and over and under controlling of stick and rudders;

b. *Narrowed span of attention* resulting in a tendency to "leave out" important elements of sequential tasks, failure to scan the whole instrument panel, slowing of the "cross check" of primary flight instrument and a tendency to "fix" on one instrument to the neglect of other equally important instruments; and

c. *Acceptance of a lowered standard of performance* and increasing preoccupation with and distraction by minor discomforts.

Much of this symptomatology is reversible, at least for some time intervals. The occurrence of any event that breaks the monotony of the task may bring the operator's skill and attention almost up to its unfatigued level. An inflight emergency, a "near miss" or even the preparations for landing will normally wipe away much of the fog which appears to cloud the flier's mind in this type of fatigue.

Our description of acute skill fatigue should include reference to an allied phenomenon which has come to be known as *vigilance* decrement, that is, a loss in one's readiness to perceive and respond to the signal inputs of watchkeeping tasks. This phenomenon is customarily measured in terms of errors of omission and prolongation of response times. Losses in vigilance are perhaps most common among radarscope observers, but they are also seen among pilots and flight engineers engaged in monitoring instrument displays. Such losses occur most readily under conditions of low signal rate in which there are unpredictable intervals between signal inputs, but other factors inherent in the design of the display system and the surrounding conditions of work cannot be ignored. The operational importance of this phenomenon can be inferred from laboratory studies which have shown that vigilance losses of 50% or more can occur within the first half hour of watchkeeping, and the existence of this problem under actual field conditions is well established.

The length of time required before acute skill fatigue becomes a hazard is extremely variable. The Royal Air Force found that significant degrees of acute skill fatigue were observable after 10 hours of flight in piston-type aircraft and after only three 1-hour sorties in jet fighters. The fatigue response was quite variable among different pilots and appeared to be more severe in night flying. Obviously, the stamina and reserve of the crew member at the time he is exposed to an acute skill fatigue will affect his ability to fight off the deleterious effects on his performance capability.

The wide variation in capability to resist the effects of acute skill fatigue which exists in various persons and within the same person at different times, makes the prediction of the onset of skill fatigue difficult at best. Only by knowing each crewmember's stamina and reserve at the time of exposure and the magnitude and quality of the fatigue-inciting events to which he is exposed, can the Flight Surgeon hope to prognosticate the time at which the crewmember will become significantly fatigued.

Chronic Flying Fatigue

Chronic flying fatigue is the term applied to the "staleness" or lowered "fatigability threshold" that results from the accumulation of residual fatigue left over from incompletely compensated recurrent acute skill fatigue.

Single episodes of acute skill fatigue can usually be corrected by a suitable rest period which gives the crewmember time to replenish his psychological and physiological reserves. For most healthy Air Force personnel, a good night's sleep is sufficient time in which to accomplish this "reknitting of the ravelled sleeve of care." However, when operational requirements dictate recurrent maximum effort missions over prolonged periods with insufficient rest and recreation to allow complete recovery from the preceding mission before undertaking the next mission, the crewmember's reserves become steadily more depleted. Acute skill fatigue tends to occur earlier in each mission and with less provocation as the crewmember becomes enmeshed in a tightening spiral of circumstances which deplete his resistance to fatigue at a steadily increasing rate.

The same etiologic factors that cause acute skill fatigue are active in chronic flying fatigue, but the crewmember's tolerance is lessened. This lessened tolerance amplifies the deleterious effects of environmental factors that were not previously significant into major stresses which take further toll of the crewmember's reserves. This is manifested by an increased awareness of discomfort, irritability, "grousing" and visible decrements in the quality of task performance and a tendency to "cut corners."

MANAGEMENT OF FATIGUE

In the ideal, and, hence, theoretical situation, fatigue is undesirable in any degree. Unfortunately, this ideal situation does not exist and we must accept the fact that fatigue is a natural and concomitant result of any demanding activity. Since the unit cannot accomplish its mission without such activity, we must accept certain minimum amounts of fatigue as a natural and implacable result of mission-oriented activity. What the Flight Surgeon must try to do is minimize the associated fatigue by minimizing or eliminating the environmental stresses that increase the amount of fatigue, but which are not absolutely necessary to the mission. It is equally important that the Flight Surgeon emphasize and advocate the factors that increase the crewmember's ability to minimize the effects of fatigue on task performance. Determining which factors are unnecessary to the mission and which can be eliminated without affecting the mission requires good judgment and close cooperation between the Flight Surgeon and the nonmedical staff members of the unit. A few of the factors that have been identified in previous studies as having positive and negative affects on fatigue levels are listed in table 12–1.

TABLE 12–1. FACTORS TO BE CONSIDERED IN ESTIMATION OF FATIGUE POTENTIALS

a. *Length of Flights:* false starts; delayed flights; waiting periods at intermediate stops.

b. *Layover Facilities:* beds; sleeping conditions; messing; recreation and diversion; ground station organization.

c. *Reliability of Radio Aids* (particularly in the arctic and around the border of hostile countries).

d. *Uncomfortable personal equipment* (oxygen masks; pressure suits; anti-immersion suits).

e. *Weather:* anticipation of bad weather; rough flying with auxiliary crew on the verge of airsickness.

f. *Physical Condition:* lack of exercise and general body tone; poor eating habits; drinking the night before flying and during intermediate stops; smoking.

g. *Human Factors Design Engineering:* seat comfort; flight-deck design; sleeping facilities; working area lighting; reliability of the aircraft; adequacy of heating and ventilating systems for arctic and tropical flights; facilities for good in-flight meals; noise and vibration levels; instrument arrangements.

h. *Toxic Factors* such as prolonged flying at 10,000 feet and slightly over without supplemental oxygen; carbon monoxide and excessive carbon dioxide in the cabin.

i. *Leadership and Team Spirit:* Relationships with aircraft commanders and with superiors on the ground; adequate support and backup;

TABLE 12-1. Continued

amount of paperwork; effectiveness with organization; amount of individual responsibility; on and off-duty responsibilities.

j. *Personal Factors:* amount of flying experience (earlier flights in a career tend to be more fatiguing); domestic difficulties; financial security; personality of the individual; motivation and conscientiousness.

k. *Diurnal Rhythm Factors.*

l. *Unforeseen Emergencies.*

A study of these factors will reveal a number of situations and conditions that can be minimized or eliminated if they are fatigue-inducing or encouraged and strengthened if they are fatigue-resisting.

In addition to his generalized, unit-wide efforts to prevent the effects of fatigue, the Flight Surgeon has an additional and awesome responsibility, namely, to identify individual crewmembers who are fatigued to the point that their performance is likely to be unsafe. Successful identification of such crewmembers requires the Flight Surgeon to have a detailed knowledge of how each crewmember normally behaves so that the earliest, minimal changes in behavior which are suggestive of fatigue can be noted and acted upon. A detailed knowledge of each crewmember's normal behavior under different environmental conditions and types of stress is gained only by continued and close association between the Flight Surgeon and the crewmember. Only in this way can the Flight Surgeon accurately perceive when the flier "just isn't himself" and thus, can identify abnormal behavioral patterns long before the customary clinical or medical laboratory tests show any abnormality.

The conscientious Flight Surgeon must try to walk the narrow line between the error of allowing dangerously fatigued crewmembers to continue flying and the error of grounding crewmembers who still can perform their tasks safely. In this latter error, overcautiousness by the Flight Surgeon causes the remaining crews to have to shoulder the additional loads of the grounded crewmembers which may result in an increased over-all "failure rate."

At all times, the Flight Surgeon should adhere to the concept that each person's fatigue problem is unique and worthy of special study in terms of the personal and situational factors which lie beneath it. This stems from the fact that no two persons react alike under the same prevailing circumstances. No other approach will go as far toward revealing the changes that may be required in the habits, attitudes, and motivational structure of the person or the environmental circumstances under which he is operating.

The role of the Unit Commander in fatigue prevention may be less scientific than that of the Flight Surgeon, but it scarcely can be regarded as less direct. Command leadership instills mission orientation, defines operational objectives, establishes level and quality of mission support, and allocates various rewards and privileges available within the natural setting of the operation. The commander is as interested as the Flight Surgeon in preventing crippling fatigue; he is receptive to professional advice on the subject and any carefully considered recommendation for environmental control that might lie within his purview. *For example,* the commanders of MAC and SAC, acting on the advice of the Flight Surgeon, improved crew facilities aboard aircraft and provided additional crewmembers to permit rotation of duties and longer rest periods. These measures resulted in more effective performance during prolonged missions.

Finally, the Flight Surgeon should employ every means available to him to consider human factors and their relationship to safe and efficient job performance. (Research facilities and personnel proficient in human factor analyses are available in the Aerospace Medical Division of the Air Force Systems Command. When required, the services of these facilities and personnel can be obtained, upon request, through normal medical channels.) The quality and consistency of work output are profoundly dependent upon equipment and work space design. Competent equipment design can be achieved only through exhaustive studies of human capabilities and limitations. Much has already been accomplished to improve comfort, range of motion, simplicity of display, organization of control complexes, and computational aids, but there is still room for improvement. The Flight Surgeon can make a valuable contribution to this effort by publicizing, through the medium of the Unsatisfactory Report or the Aerospace Medicine Report, the comments and criticisms made by aircrewmembers concerning their equipment and work methods.

It has been found that intensive training will build up confidence and permit more relaxed flying responses. As a result, inflight emergencies and the ground controlled approach (GCA) at destination become less troublesome to the trained crewmember. In the case of simulators, indoctrination on skill fatigue leads to significant performance improvement. Frequently, fatigue simply signals the need for a few moments of variety and change to restore performance. In industry, when workers have been given breaks, output has been found to be superior to that produced by working continuously.

Coffee should be reserved for the last half of a flight since many people get a postcaffeine letdown. Similarly, meals should be balanced rather than relying on pure carbohydrate, since an insulin over-shoot may produce delayed hypoglycemia. The person in a good physical condition has greater ability to tolerate fatigue, experiences less postural tiring, and recovers faster after the mission.

Dextroamphetamine has been administered to a large number of aircrews without an accident attributable to the drug. However, side reactions have occurred in flight. To cite a case, one F-100 pilot who had been pretested as required and showed no side effects, took his first 5 mgm dexedrine before a refueling over the mid-Atlantic. He experienced a feeling of euphoria with a narrowed span of attention and complained that he could think of only one procedure at a time. Others have noted agitation and hyperactivity. Attention to crew rest facilities in larger aircraft has obviated the requirement for stimulants on many missions and constitutes a much better approach to the problem.

Unquestionably, fatigue will be a major problem in future space operations. The prolonged nature of such missions, coupled with periods of unpowered orbital flight en route, a minimal input workload and associated monotony, will create fatigue problems of considerable magnitude.

Although fatigue is a basic response of the human to continued stress, it can be minimized through a system of crew and environmental controls. The Flight Surgeon should be vitally interested in operational problems and their investigation and should serve as an advisor to the operational commander in the planning and evaluation of systems application to man.

REFERENCES

The reader should insure the currency of listed references.

Bartlett, F. C., *Fatigue Following Highly Skilled Work* (Ferrier Lecture), Society of London, Series B., Biological Sciences, Volume 131:247-257 (1942).

Bartley, S. H., and Chute, E., *Fatigue and Impairment in Man*, New York, McGraw-Hill (1947).

Davis, D. R., *Psychomotor Effects of Analeptics and Their Relation to "Fatigue" Phenomena in Aircrew*, British Medical Bulletin, Part I, Volume 5, No. 1 (1947).

Davis, D. R., *Pilot Error*, Air Ministry, A. P. 3139 A. London, His Majesty's Stationery Office (1948).

Floyd, W. F., and Welford, A. T. (eds): *Symposium on Fatigue*, London, H. K. Lewis (1953).

Fraser, D. C., *Study of Fatigue in Aircrews*, Flying Personnel Research Committee Reports of Great Britain #984 (1957).

McFarland: *Human Factors in Air Transportation*, McGraw-Hill (1953).

Reid, C., *Mechanism of Muscular Fatigue,* Quarterly Journal of Experimental Physiology, 19:17–42 (1928).

Schreuder, O. B., *Medical Aspects of Aircraft Pilot Fatigue with Special Reference to the Commercial Jet Pilot,* Aerospace Medicine, 37:4 Section II (1966).

Stanbridge, R. H., *Fatigue in Aircrew: Observations in the Berlin Airlift,* Lancet 261, No. 6671, 1–3 (1951).

Strughold, H., *Physiologic Day-Night Cycle After Long-Distance Flights,* International Record of Medicine and General Practice Clinics, 168:576–579 (1955).

Weiss, B., and Laties, V. G., *Enhancement of Human Performance by Caffeine and the Amphetamines,* Pharmacological Reviews, 14:1–36 (1962).

Whittingham, Sir Harold, *On Flight Time Fatigue,* Flying Personnel Research Committee Reports of Great Britain #FPRC 1037.

Chapter 13

AIRCREW NUTRITION

Nutrition is of basic importance to all fighting forces and has particular application in the Air Force to flight requirements for aircrews. The feeding procedures which accomplish the goals of nutrition will be considered in three parts: the *Ground Feeding Program,* as related to personnel garrisoned at Air Force bases; the *Flight Feeding Program,* unique to airborne situations; and the *Survival Feeding Program,* which attempts to nutritionally sustain the airmen isolated in hostile or primeval territory.

Ground Feeding

The ground feeding of Air Force personnel is conducted in base dining halls or cafeterias on a plan common with that of the US Army. Under this system, all ration supplies are procured and distributed through the Defense Personnel Support Center, based on the variety of complete meal menus circulated months in advance by a Joint Army-Air Force Master Menu Board. These master menus are planned in accordance with the nutritional standards prescribed in AFR 160-95. The dietary standards should be maintained when later adjustments of the menus become necessary because of local climatic, personnel, or supply conditions.

Final local changes in meal menus are authorized and should be coordinated by base menu boards on which the food service supervisor, commissary officer, and surgeon are represented. This arrangement is designed to insure satisfactory ground feeding despite the complexities and global scope of Air Force operations.

The principal standard ration for ground use, Field Ration A, is the one normally issued to Air Force units when both kitchen and refrigeration facilities are available. It includes many varieties of fresh, perishable food components, as listed in master menus and served regularly at bases in the CONUS. When such perishables cannot be stocked at oversea or field locations, usually because refrigeration facilities are lacking, the operational B Ration is supplied as the standard dining hall ration. The B Ration substitutes, canned or dehydrated, are nonperishable items of the same types as in Field Ration A, for feeding groups of approximately fifty or more men.

Smaller Air Force units, when separated from kitchen facilities for temporary periods, can subsist adequately on Ration, Small Detachment, 5-in-1. Each packaged ration of this type provides food for five men for one day and is eaten either hot or cold. Its use in the Air Force is usually limited to emergency reserves for advanced radar and weather detachments, crash crews, and search and rescue operations.

Other ground-type packaged rations, or specialized supplements, are listed and described in TO No. 00-35A-36, "Operational Rations, Food Packets, and Supplements." These include Ration Supplements for hospitals or aid stations, the Ration, Individual, Combat, and Ration Arctic Trail. The last two named are primarily intended for Army field forces under combat conditions. They are designed to provide food for one man for one day, and apply rather infrequently to Air Force requirements.

Flight Feeding

Flight feeding is considered in three categories: preflight, in-flight, and postflight. These are specialized extensions to the basic program of nutrition on the ground. All have become increasingly necessary in recent years because of the extended ranges and performance of modern aircraft.

It is recognized that flying activities often interrupt and modify the fundamental living habits of personnel, including those of sleeping, eating, or drinking. The primary purpose behind flight feeding efforts is, accordingly, to assist aircrews and also aircraft passengers in their adjustment to these work demands.

Field observations from various sources have indicated that "nonfeeding," or irregular eating practices over an extended period, contribute to fatigue, human error, and possible aircraft accidents. The value of flight feeding with respect to general bodily comfort and morale is even more commonly recognized. To promote the best in performance, the flight feeding system should properly "refuel" the human operators with nutrients, on a careful and regular basis, just as an aircraft is refueled.

The three categories of flight feeding are regarded as consecutive phases, differing only in details of purpose and methods of accomplishment. Preflight and postflight feeding are implemented through ground-kitchen facilities. They may be readily available and effective at some Air Force bases, but not available at others. In-flight feeding is comparatively more difficult because the limitations of aircraft restrict food preparation and consumption. The two ground phases should therefore be planned to counterbalance and compensate for any in-flight periods of a marked nutritional deficit.

Food servicing is often a matter of individual responsibility. Personnel frequently obtain separate flight subsistence from Air Force supply sources, commercial stores and restaurants, or their respective homes. This means that all airmen should be trained to follow conscientiously a good dietary pattern.

Preflight Feeding

Effective preflight preparations require that each person boarding an aircraft should consume a freshly-prepared, balanced meal an hour or two before expected takeoff. This usually is a breakfast menu of fairly light proportions, even though it may be scheduled at various times of day or night. Under pleasant, unhurried eating conditions, a desirable relaxation and a regularity of digestion are encouraged.

Fighter pilots and some bomber crews may require further diet control to reduce the incidence of gas pains and improve crew effectiveness at high altitudes. Specific fixed diets are not entirely satisfactory because of the marked variability in food tolerances and preferences between individuals. Balanced meals containing good quality protein, as well as carbohydrate, and also free of foods producing flatulence or bulk in the colon, are considered generally acceptable. (*Note:* The High Protein, Low Residue Diet recommended for special preflight conditioning is in AFM 146-2.)

Items contraindicated, because they induce abdominal gas, include vegetables of the cabbage family, dried peas and beans, beer or carbonated drinks, turnips, rutabagas, and other raw fruits or vegetables which are fibrous. The chewing of gum is also discouraged since it promotes air swallowing. Many fresh fruits and fruit juices are permitted and may prevent depletion of Vitamin C from repeated altitude exposure. High-fat, heavily spiced, or poorly-cooked food items are less readily digested, and generally avoided by aircrews. Field reports indicate that the occurrence and severity of gastric distress in flying are quite low when moderate dietary precautions are taken.

Alert-crew feeding is a special situation of preflight feeding. When crewmen are on alert-crew status, they are restricted to the alert-crew hangar and must be ready at all times for immediate takeoff. AFM 146-2 authorizes local commanders to establish special dining facilities for this situation, both preflight and postflight. Food items authorized by AFM 145-1 and/or precooked frozen meals and food packets, individual, in-flight (IF), are authorized for alert-crew feeding.

In-flight Feeding

In-flight feeding is a rather new development in comparison with other aircraft procedures. Early aircraft had short flight durations which did not require organized feeding in the air; but the importance and need for such provisions became apparent during World War II. The present concepts of in-flight nutrition have evolved from the increasing requirements of aircrews for longer missions, as the result of current range-extension developments. Some degree of in-flight feeding is now routine in most Air Force operations.

The factors which influence the extent and success of food servicing in an aircraft are numerous. Meals eaten aloft are often a nutritional compromise with the practical realities of limited aircraft space, equipment, and other demands of the flying situation. Accordingly, no single method of in-flight feeding or standard type of food packaging can completely fulfill all of the changing needs of fliers. The satisfactory feeding operation must feature simplicity, ease of support, and a variety of well-liked foods and beverages in attractive combinations. To some extent, this requires a different "prescription" of meal types and food servicing equipment for each model of aircraft and also for each kind of flight mission.

Air Force equipment directives plan for drinking fluids to be supplied in all aircraft capable of flying over 3 hours, in quantities of one quart per crew member or passenger for each 16 hours of flight. Flight lunch storage and heating facilities are similarly scheduled for aircraft with over 6 hours' flight duration, on the basis of one added meal for each subsequent 6 hours. This criterion serves only as a guide for the initial authorization, design, and production of feeding apparatus or food packets.

These planning figures will be much more flexible as the actual feeding practices are worked out within the operational Air Force commands. For example, the aircraft flight time has not proved a true index for in-flight feeding. The "flight duration" for this purpose should be the total time from the preflight breakfast (or last meal before takeoff) to the end of postflight debriefing or interrogation.

Field observations show trends in aircrew feeding habits that are common enough between Air Force commands to be classed as "in-flight peculiarities." The appetites of crew personnel usually decrease, especially in the final hours of long flights, and food items are regarded more critically. Features of the military aircraft environment, such as work concentration, noise, vibration, decreased oxygen, etc., all tend to reduce the digestive processes. The extreme tensions of air emergencies and active combat may completely inhibit gastric function.

The taste acceptability of certain food items may differ between ground level and altitude, for reasons other than jaded appetite, excitement, or fatigue stress. Some comparative acceptance studies indicate that potatoes, vegetables, and salads are rated about 20% lower in the air than on the ground; soups, meats, fruits, and beverages are roughly comparable in both environments; baked goods and desserts are highly palatable in all flight circumstances.

Monotony of diet is a further in-flight problem for aircrews, which does not apply to airborne troops and passengers who travel less frequently. Passenger personnel generally consume heavier meals, presumably to relieve flight strain or tedium. Their eating also prevents the "emptiness" and other gastric discomfort which seem to predispose to airsickness in certain susceptible individuals.

Approximately 6 hours are recommended between in-flight meals (AFM 146-2), but small amounts of "free choice," sugar-yielding food supplements are desirable between the meal periods. Beverages are most important and should be freely available at all times. These factors are presented as a guide to the average in-flight practices of the majority of operational personnel, rather than as arbitrary and fixed requirements.

Types of Meals Authorized

To avoid excessive repetition in serving similar meals, with resultant decreases in acceptability, the seven types of flight meals listed below are authorized. Other types of flight meals may be used only when authorized by HQ USAF.

a. *Flight Meals Authorized for General Use.* These meals should be used interchangeably so far as flying schedules, special equipment, and missions permit.

(1) *Food Packet, Individual, In-Flight, (IF).* This packet contains canned items and is designed for use at bases where fresh foods are not available or cannot be stored in aircraft without spoilage. Each packet is a complete meal in itself, and ten different menus are assembled in the separate packets. Their storage stability is approximately 2 years. These in-flight food packets contain an average of 1,200 calories. They have proved very acceptable when consumed at irregular periods.

Each food packet contains four cans: one of meat, one of fruit, one of dessert, and one of juice. There are ten menus that include four varieties of fruit, ten kinds of meat items, six dessert selections, and four varieties of juice.

Specific components are:

Meats	
Beef, with spiced sauce	Ham, fried
Beefsteak	Ground meat and spaghetti
Chicken and noodles	Pork steak
Chicken	Turkey loaf
Ham and Eggs, chopped	Tuna fish
Fruits	
Apricots	Pears
Fruit cocktail	Peaches
Desserts	
Cookies	Pound cake
Fruitcake	Pecan cake roll
Orange nut roll	Chocolate nut roll
Juices	
Grapefruit-orange	Grape
Orange	Tomato

In addition, each menu contains an accessory packet with individual servings of soluble cream, coffee and tea, sugar, plus chewing gum. The food items have all been cooked and may be eaten cold; but the flavor of the meat items and date pudding is enhanced by heating. Several types of food warming devices have been authorized for use on aircraft.

This food packet is the most versatile in-flight meal. It is nonperishable and may be used in the majority of aircraft, is available on short notice through regular channels of supply (commissaries, personal equipment offices, and/or flight kitchens), and requires a minimum of aircraft servicing equipment.

(2) *Precooked Frozen Meal.* The main dishes of the precooked frozen meal are centrally procured and are issued through commissary supply channels. Supplemental items including bread, salad, beverage, and dessert are issued by the flight kitchen to the crewman.

There are 5 menus available:

Menu No.

1. Turkey, dressing and gravy, mashed sweet potatoes.
2. Swiss steak with gravy, peas, au gratin potatoes.
3. Beef steak, corn, and mashed potatoes.
4. Beef pot roast, green beans, mashed potatoes.
5. Waffles, sausage links, applesauce.

Menus 1 through 4 are dinner meals and menu 5 is a breakfast meal. A sixth meal is being added to the selection in the near future.

Aircraft ovens and refrigerators are required for storage and preparation of all menus.

These meals are procured quarterly, and the cartons are dated when the meal is produced. For best acceptability, they should be consumed within 9 months from date of manufacture.

A plastic vial, half filled with water and frozen in a vertical position, is placed in each case in a lateral postion. If the ice has melted and flowed along the axis of the tube, the meals are not to be consumed. The melted ice is evidence that the temperature has been high enough that Staphylococcal toxins may be present.

(3) *Sandwich Meal.* The Sandwich Meal is by far the most common type and is prepared as a standard Air Force package in dining halls or by special flight kitchens. It consists of fresh sandwiches, milk, canned juices, fresh fruit or desserts, plus additional items, such as celery, pickles, and hard-boiled eggs. (See illustration.) Various nutrition-

Figure 13–1. Individual In-flight Packet.

Figure 13–2. Casserole and Tray Type Precooked Frozen Meals.

Figure 13–3. A Typical Sandwich Meal.

Figure 13–4. Foil-Pack Meal.

ally-balanced combinations are in AFM 146–2; but their essential freshness, appearance, and appetite appeal depend on the resourcefulness of the kitchen personnel.

The most acceptable sandwiches are those containing sliced meats, chicken, or turkey; with bone, bone splinters, and inedible gristle removed. The sandwiches should be wrapped immediately after preparation in waxed paper sandwich bags, and refrigerated below 40° F until issued to crew members. No gravy, chopped egg, or chopped meat fillings should be issued because of the increased danger of bacterial food poisoning. (See AFM 161–6 for recommended refrigeration and consumption procedures.)

After 5 or more hours at room temperatures, most types of sandwiches or other perishables can become unsafe for consumption through toxin production resulting from bacterial growth. Therefore, all sandwich components not consumed within 5 hours of preparation or issue will be destroyed. The sandwich lunch is most useful in that it requires no installed aircraft equipment and is generally well liked if not too frequently repeated. It is usually limited to short flights or as the first meal of long missions.

(4) *Precooked Hot Meal and Breakfast Meal.* AFM 146–2 authorizes the use of both the precooked hot meal and the breakfast meal. These meals are rarely used inflight, however. The precooked hot meal is prepared as a hot meal on the ground and is placed aboard the aircraft in an insulated container or warming oven. The meal is kept heated until consumed. This meal has poor keeping qualities. It is unpalatable if held too long, so it cannot be used in the later hours of a long flight. The meal is also unsatisfactory if takeoff time is delayed greatly.

The breakfast meal consists of ready-to-

Figure 13–5. Insulated Jug With Capacity of Two Gallons.

Figure 13–6. Experimental Can-Piercing Drinking Device Showing "Closed System" Looped Drinking Tube for Equalizing Pressure Within Can.

Figure 13–7. Experimental Can-Piercing Drinking Device Showing Disposable Mouthpiece, Proposed for Air Evacuation Patients.

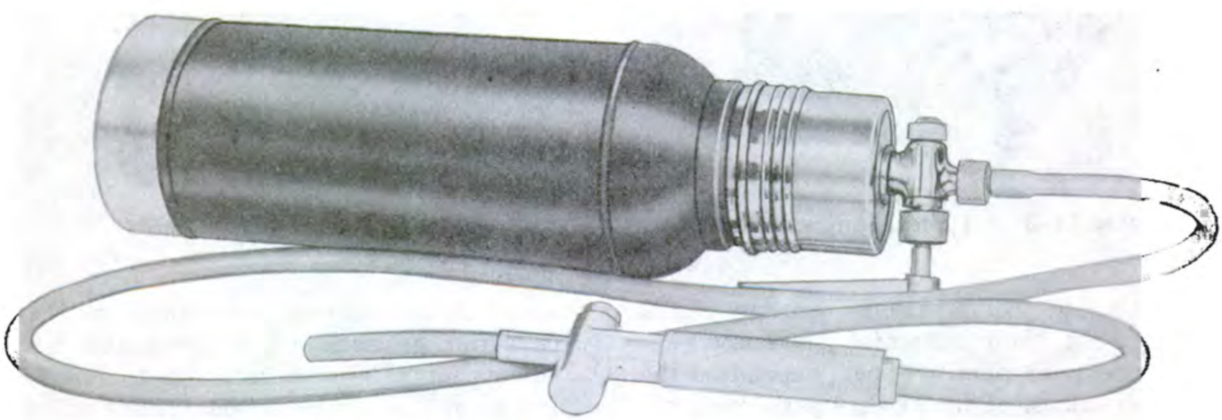


Figure 13–8. Crew Position Water Bottle Assembly.

Figure 13–9. Experimental Can-Piercing Drinking Device, Complete Kit Assembly.

eat breakfast items taken aboard for assembly in-flight. Breakfast meals are rarely required in-flight, since most passengers and crewmen desire heavier food by the time they are airborne, even on early morning flights.

The precooked hot meal and breakfast meal should not ordinarily be considered for flight feeding except under unusual circumstances.

(5) *Bulk Issue for Preparation Aloft.* Authority is granted to issue, in bulk, the food components authorized in addition to those normally stocked by the flight kitchen. For other types of flights, meals will be procured directly from the commissary store by the aircraft commander or his designated representative.

b. *Flight Meals Authorized for Specific Use.*

(1) *Bite-Size Meal.* The bite-size meal is authorized for jet aircraft when the serving of any other type of flight meal is not practical. All components must be "bite-size" and suitable for eating by hand. Each package will be clearly marked with the date and time limit of safe consumption. This meal will be consumed no later than 5 hours after preparation. The bite-size meal consists of the following components:

Beverage Unit: Milk or juice.

Meat Component: Cubes of cooked steak or other lean, tender meats.

Dessert Component: Cookies or pieces of fruit, and candy.

Optional Items: Gum, relishes, nuts, coffee.

(2) *Foil-Pack Meal.* The foil-pack feeding system has been authorized for use at certain bases supporting particular type operations, such as radar picket patrol missions. This system is designed primarily for large aircraft where space and power are available and where weight is not a limiting factor. The Strategic Air Command first demonstrated the possibilities of this procedure, using the type B-4 oven supplied with B-36 aircraft. In their preliminary trials, a number of fresh-chilled food ingredients were prepared and cooked with marked success in hand-assembled, aluminum-foil packages.

This foil-pack meal at present consists of five menu items in separate containers: meat, two vegetables (potato and another vegetable), hot roll, and dessert. Four breakfast menus are available from the total of sixty-eight menus that have been developed. Except for the packaging of rolls, pies, cakes, and the searing of meat in ground kitchens, all items are packaged uncooked in separate, rectangular foil containers. These are sealed with a top cover, combined as a meal on single trays, and refrigerated (37° F) until the time of final cooking.

The system utilizes three special articles of equipment: aluminum foil packs and crimp-closure device, aircraft refrigerator, and oven. The meals, packaged very simply in ground-support kitchens, are composed of the common, lower cost, dining hall subsistence supplies, and require minimum training and effort of aircrews. This meal has very high acceptability and is very popular at the installations using them.

Beverages

Dehydration of the human body results in lowered efficiency and is a serious factor for flight operations in hot climates or at high altitude. Cool water, coffee, tea, chocolate milk, tomato juice and fruit juices are all popular. Cool water should always be available, and other beverages should be available on missions of more than a few hours. Beverages should also be included with flight meals. However, gratuitous issue of Government beverages to passengers and crews between meals is not authorized.

The following liquid-feeding equipment is available. One or 2-gallon containers are usually used in passenger, cargo, and bomber aircraft where large numbers of people must be served and where mobility of crew members is permitted. The recommended 2-gallon capacity container is the "Jug, Insulated, type CNU-2/C"; standard, specification MIL-J-25718, as illustrated. It is rectangular in shape and is fabricated of stainless steel, has an electrical element which will operate on either 28 Volts DC or 115 Volts AC, and is designed to keep liquids between the temperatures of 170° and 190° F as long as power is supplied.

The jug can also be charged with wet ice to keep beverages cool. With an initial full charge of ice, at an ambient temperature of 90° F, the liquid temperature can be kept below 45° F for a period of from 16 to 25 hours. The type CNU–2/C jug replaces the type J–1 container with dry ice well, which is now limited standard.

An alternate 2-gallon container, which can be used when electrical power is not available or where a cylindrical shape is desired, is the type III, Grade A, Class 2 Insulated Jug described by specification MIL–C–3164. The construction of this container is also of stainless steel and is available in the 1-gallon as well as the 2-gallon size. The jugs are designed to keep beverages above an acceptably warm temperature for a period of at least 6 hours at an ambient temperature of 68-76° F. This type jug replaces the old type F–1 liquid containers which are now limited standard.

Special equipment is available for fighter aircraft and for situations where the crew member must remain in a fixed position for an extended period of time. Crew position water bottle assemblies, here illustrated, of the 1-quart horizontally installed, and 2-quart vertically installed types are now standard-issue items. Each assembly consists of a stainless steel vacuum bottle with cap, sealing gasket, and spigot equipped with a vent tube to allow liquid to drain from the bottle.

The liquid outlet of the spigot is attached to a length of silicone rubber tubing, having a teflon drinking probe. A handset valve is used to govern the flow of fluid. The container is mounted so that the liquid will flow

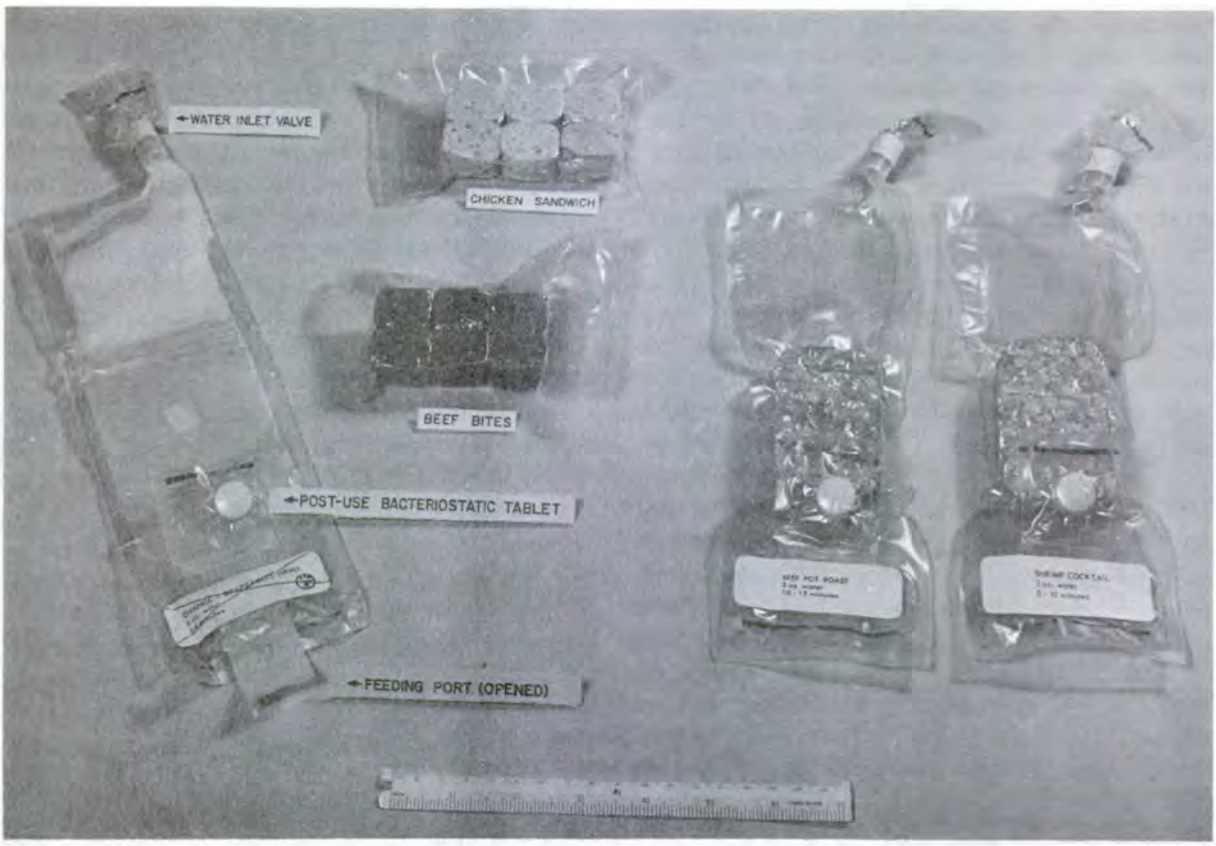


Figure 13–10. Typical Space Meal in Zero–G Feeders.

Figure 13-11. B-4 Oven With Foil-Pack Meals on Lower Shelves.

Figure 13-12. B-3 Oven With IF-Food Packet Cans in Place for Heating.

by gravity to the point of consumption. The bottles are designed to keep liquids above an acceptably warm temperature for a period of at least 6 hours at an ambient temperature of 77° F.

A device has been developed for piercing commercial juice and beverage cans and provides for drinking the liquid directly from the can. Refer to the accompanying illustration. This device is contained in the "Dispensing Kit-Liquid Can Piercing-Drinking" which is described by USAF Dwg. No. 54B3827.

New Foods for Special Aerospace Operations

Low-moisture foods have been developed for feeding systems in space vehicles where the environment and weight and volume limitations have required highly stable, lightweight rations which require minimum preparation. These feeding systems are composed of bite-size dehydrated foods, rehydratable precooked freeze-dried foods and rehydratable beverages. These foods packaged in flight-qualified packaging material are stable for 2 years or longer at room temperature (see figure 13-10).

Foods developed for in-flight feeding in fighter aircraft are currently being tested in operational aircraft. Bite-size foods similar to those used in space feeding have been produced in large quantities for test in aircraft which require the wearing of an oxygen mask. Tube foods, liquid-formula foods, and rod-shaped foods are being developed for operational aircraft which require the continuous wearing of a full pressure suit. Details of completed studies on evaluations of foods for space feeding and other special aerospace operations are contained in Technical Reports distributed from the USAF School of Aerospace Medicine, Brooks Air Force Base, Texas.

Equipment

Food Servicing Equipment has been briefly referenced in preceding sections, but a number of additional items also exist, either recently developed or previously standardized for aircraft supply. When such apparatus can be made readily available to aircrews,

TABLE 13-1. *FOOD SERVICING EQUIPMENT FOR AIRCRAFT

Bracket and Receptacle, Hot Cup, Four Unit, 28 volts, Type A-1 Spec MIL-B-7528 (Standard)
Bracket and Receptacle, Hot Cup, Single Unit, 28 volts, Type A-2 Spec MIL-B-7526 (Standard)
Bracket and Receptacle, Hot Cup, Four Unit, 115 volts, Type B-1 Spec MIL-B-7527 (Standard)
Bracket and Receptacle, Hot Cup, Single Unit, 115 volts, Type B-2 Spec MIL-B-7527 (Standard)
Bracket and Receptacle, Hot Cup, 115 volts, Single Unit, Type B-2 Spec MIL-B-7525 (Standard)
Cup, Food Warming, Electrically Heated, Aircraft, Type A-1 28 volts, Spec MIL-C-7615 (Standard)
Cup, Food Warming, Electrically Heated, Aircraft, Type B-1 115 volts, Spec MIL-C-7561 (Standard)
Cups and Lids, Paper, Hot Food or Drink, Style A, 603 Spec UU-C-8344 (Commercial Standard)
Dispenser, Paper Drinking Cup, Wall Mounted, Aircraft, 24 Cup Capacity (USAF Dwg No. 49D3786)
Dispensing Kit, Liquid Can Piercing, Drinking (USAF Dwg No. 54B3827) (Standard)
Jug, Insulated, Type CNU-2/c (2 Gal.) Spec MIL-J-25718 (Standard)
Jug, Insulated, Type III, Grade A, Class 2, 1 Gal. and 2 Gal. Spec MIL-C-3164A (Commercial Standard)
Oven, Food Warming, Electrically Heated, Type B-4 Spec MIL-O-6438B (Standard)
Refrigerator, Dry Ice, Precooked Frozen Food Storage, Type B-1, Weber Aircraft Corp., Burbank, Cal., Dwg. No. R72202 (Com. Stand.)
Refrigerator, Mechanical, Non Frozen Storage, 4 cu ft, Model SR-4, Dale Sales, Inc., Los Angeles, Cal. (Com. Stand.)
Refrigerator, Mechanical, Non Frozen Storage, 6 cu ft, Model SR-6, Dale Sales Inc., Los Angeles (Commercial Stand.)
Refrigerator, Mechanical, Non Frozen Storage, 12 cu ft, Model SR-6A, Dale Sales Inc., Los Angeles (Commercial Stand.)
Refrigerator, Mechanical, Frozen and Non Frozen Storage, 10 cu ft, Model SR-10, Dale Sales Inc., Los Angeles (Commercial Stand.)
Tray, Inflight, Food Servicing, Disposable Spec MIL-T-8166 (Commercial Standard)
Water Bottle Assemblies, Crew Position, 2 qt Horizontal, 2 qt Vertical, 1 qt Horizontal, 1 qt Vertical Spec MIL-B-25337 (Standard)

*Subject to change.

the occurrence of in-flight feeding problems and deficiencies should proportionately diminish. Principal types of equipment items are listed in table 13–1, and are discussed in the following paragraphs.

The B–4 in-flight feeding oven, as illustrated, is intended to be used to heat precooked frozen meals, foil-pack meals and IF canned components in aircraft using 28 volt DC, 120 volt single phase AC and 208 volt three phase AC. The oven has six removable shelves, each with a 375-watt heating element, which can be respaced or heated separately. There is a 175-watt heating element in the side wall to hold foods warm at 150-160° F.

The maximum power drain of the oven is 2425 watts. Its weight is 21 lbs. The oven will warm six precooked frozen meals, six foil-pack meals or 18 IF canned meat components in a period of approximately 30 minutes. Further information regarding the oven can be obtained from specification MIL–O–6438B (USAF) and technical orders 13B1–2–1 and 13B1–2–4. The B–4 oven is being replaced by a new, forced-air oven of superior design and versatility.

The type B–3 oven, here shown, was designed for warming canned IF food-packet components, and cans of "ready to serve" type soups in aircraft using either 28 volt DC or 115 volt single phase AC power. The

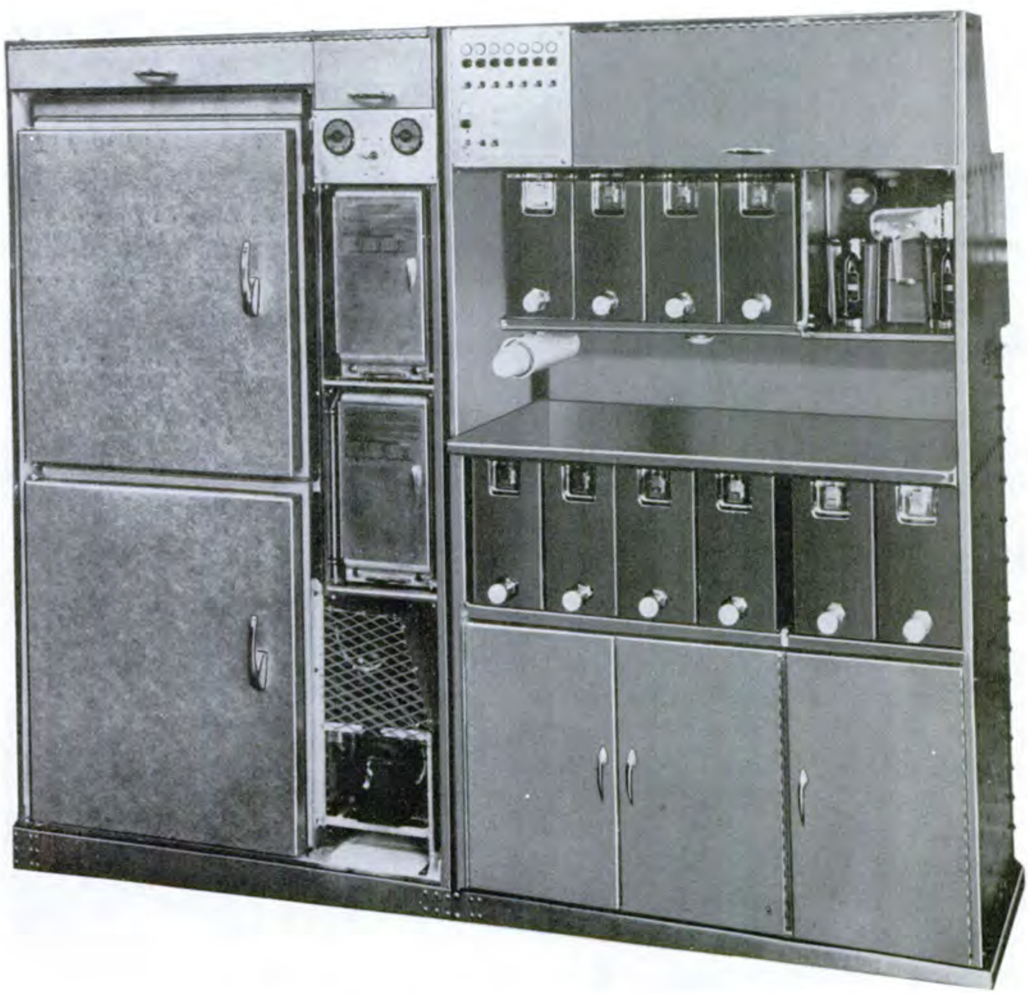


Figure 13–13. Completely Equipped Galley.

capacity of the oven is eight cans which can be heated to palatable temperatures in 10 to 20 minutes, depending upon the initial can temperature. The type B-3 oven has a total wattage of 920, with one 400-watt element embedded in each of two shelves and a 120-watt "holding" element located in a side wall. Maximum weight of the unit is 8¾ pounds. This oven is no longer available from supply. The B-4 oven previously described is used as a replacement.

Galleys

Aircraft food galleys consist essentially of a framework incorporating a storage space, a work surface and various items of insert equipment, as the illustration shows. Specifications MIL-G-25608A and MIL-G-25607 cover respectively the design and testing of galleys. The current practice is to design a different galley in accordance with the physical space available, and the feeding requirements on each type aircraft.

It is recommmended in specification MIL-G-25608A, that insert equipment be selected from the following list:

a. Rectangular liquid containers per MIL-J-25718.

b. Type B-4 ovens per MIL-O-6438.

c. Hot-cup brackets per MIL-B-7525, MIL-B-7526, MIL-B-7527, or MIL-B-7528. (Hot-cup brackets may be designed into the galley with the approval of the procuring activity.)

d. Hot-cups per MIL-C-7561 and/or MIL-C-7615.

e. Drinking-cup dispensers.

f. Refuse container and disposal facilities.

g. Swing-a-way type, or equal, can opener.

h. Refrigerator (mechanical, dry ice, or other approved type).

i. Other insert equipment approved by the procuring activity.

A water tank, sink or drainage part, and accessory plumbing may also be included in the galley.

Figure 13-14. The Hot Cup, Mounting Bracket, and Timer.

Hot-Cups and Brackets

The type A-1 hot-cup is designed to operate on 28-volt DC, and the type B-1 hot-cup is designed to operate on 115-volt AC. The cups have a capacity of 37 fluid ounces and are designed to provide hot water for reconstituting beverage concentrates; for heating two un-opened 211 x 304 single-strength soup cans or three 300 x 200 IF ration cans in boiling water; and to warm liquid and semisolid foods directly.

Since aircraft facilities seldom permit adequate cleaning of food solids from the cup, its use for substances other than water is not recommended. When filled to the brim with water at 70° F (ambient temperature 77° F), the cups are designed to heat the water to 212° F within 10 minutes. One unit and four brackets with receptacles, timers, and warning lights are available for each of the 28-volt and 115-volt cups.

Mechanical Refrigerators

The type C-1 mechanical sectional refrigerator has been succeeded by mechanical models with better operating characteristics. The following models, manufactured by Dale Sales, Inc., Los Angeles, California, are now in use in the Air Force.

Model SR-4 is a 4-cubic foot refrigerator designed to keep food in the temperature range of 32-45° F. It has a small ice-cube compartment. Outside dimensions of the refrigerator are 34½" high x 24" wide x 24" deep.

Figure 13-15. Mechanical Refrigerator SR-6A.

Model SR-6 has a volume of 6 cubic feet. It will maintain food in the temperature range of 32-45° F, and will accommodate 52 foil-pack or precooked frozen meals (provided conditions permit thawing of the frozen meals). A forced air system circulation provides rapid pull down and even distribution of temperature. The box has no ice cube compartment. Outside dimensions of the refrigerator are 33″ high x 27″ wide x 18⅝″ deep. A refrigeration unit 12-9/16″ wide x 20½″ high x 18⅝″ deep extends from either the left or right side or from the rear panel.

Model SR-6A, here illustrated, has a volume of 12 cubic feet and consists of a basic SF-6 unit with a stack-on section of equal volume. The refrigerator is designed to maintain an internal temperature range of 32-45° F and to hold 104 foil-pack or precooked frozen meals (provided conditions permit thawing of the frozen meals). The SR-6A has the same rapid temperature pull down characteristics as the model SR-6. Outside dimensions are 63″ high x 27″ wide x 18⅝″ deep. It also has an additional refrigeration side unit similar to model SR-6.

Model SR-10 is a dual-temperature refrigerator. The six-cubic-foot upper chamber can be regulated for +40° F or −10° F and will hold 126 precooked frozen or 98 foil-pack meals. A lower 4-cubic-foot section is adjusted for 40° F only, and is designed for the storage of milk, butter, fruits, bread, etc. Outside dimensions are 58″ high x 24″ wide x 24″ deep. A refrigeration unit 25″ high x 24″ wide x 11″ deep joins the box on either the right or left side or the rear panel.

Dry Ice Refrigerator

The type B-1 refrigerator is an insulated aluminum box that holds 60 pounds of dry ice in a center well, and 32 frozen meals on the sides. When packed in this way, it will maintain the meals between 0° and 20° F for 48 hours at an outside ambient temperature of 90° F.

Minor Items

A disposable pasteboard tray has been designed to accommodate IF cans, foil-pack, and precooked frozen meals.

Packet, Accessory, In-Flight Feeding, Type I, is an accessory cellophane packet for use with precooked frozen and foil-pack meals, containing plastic knife, fork and spoon, salt envelope, pepper envelope and paper napkins. The Type II Packet is intended for use with sandwich-snack meals, consisting of plastic spoon, salt envelope, pepper envelope, and paper napkin.

Some work has been done in the past to develop a disposable refuse container. Most galleys are now provided with a metal refuse container. It has been found that satisfactory watertight, disposable inner liners for the refuse containers can be made from polyethylene tubing, cut into lengths, and heat-sealed on one end.

Microbiology of Flight Meals. Food-borne infections are always distressing and become particularly serious when the symptoms develop during flight. These may occur when the perishable components of preflight and

Figure 13–16. Refrigerator, With Center Well for Dry Ice.

in-flight meals are improperly handled. Continuous preventive control is necessary, including ground-kitchen sanitation and refrigerated storage of packaged in-flight meals on the flight line or aboard aircraft. This involves the time-temperature factors of bacterial growth in foods prior to consumption and also the design, use, and cleaning of all servicing equipment. (See AFM 161–6 for recommended refrigeration and consumption procedures.)

Microbiological studies delineate the approximate temperature range of 50-130° F as the zone in which food infection organisms multiply and exterotoxin can be produced by microorganisms. The minimum incubation period for bacterial growth of hazardous proportions is generally five hours. The safe supply of perishable flight foods therefore demands: sanitary practices to preclude inoculation of pathogens during ground stages of food preparation and to reduce all bacterial contaminants in number; holding at incubation temperatures (above 50° F) no longer than 5 hours before consumption; and maximum use of refrigeration (below 50° F), or alternatively heating to above 130° F for continuous periods before serving.

These principles apply to any type of in-flight perishable meal items (for example, sandwiches, snack lunches, and hot meals), whether originating from flight kitchen, commercial courses, or household supplies. Individual packaging in disposable, sanitized containers is a desirable supplementary protection in view of the limited hygienic facilities of military aircraft.

Repeated bacteriological analyses have been made on the perishable in-flight foods, especially the more complex precooked frozen meals and foil-pack meals. The bacterial counts are sufficiently low to indicate minimal hazard in such feeding, provided that carefully organized supply procedures are followed. Aircraft food heating equipment also provides temperatures above 165° F which inhibit and often destroy food bacteria of pathogenic significance. However, such high temperatures will not inactivate the more stable enterotoxins if already formed in food prior to heating. Complete cooling or freezing is the essential for all protracted periods of transport and storage.

The establishment of consistent bacterial safeguards greatly determines the types of food perishables that can be utilized in aircraft. This is dependent upon the efforts and training of personnel directly responsible for the conduct of flight feeding in the operational commands.

Postflight Feeding

The postflight phase depends considerably upon the physical and mental condition of the returning airmen, as affected by the operating and nutritional demands of the completed flight period. Postflight feeding stimulates both physiological processes and morale, helping to shorten time lost between missions and to prevent chronic fatigue. For these reasons, it should not be long delayed, and convenient flight-line kitchen facilities are a requisite.

One purpose of eating at this time is to relax tensions induced by long hours of alert concentration or other fatiguing flight pressures. Extreme cases may justify the special provision of some light refreshments (*for example,* beverages, ice cream, or juices) before or during such postflight duties as interrogations. This would be preliminary to a later more complete dinner meal in which protein is predominant in the menu. Some degree of feeding is routinely indicated as the first measure of rest and recuperation.

Survival Feeding

Survival situations are emergencies of bailout, ditching, or other forced landings into primitive isolated regions or behind enemy lines. In the "struggle for existence" toward escape and ultimate rescue, the availability of water and food may be critical. The emergency parachute kits, or life rafts and clothing stowed in military aircraft, are accordingly designed to carry the equipment and the foods necessary for survival.

It is anticipated that survivors will undergo some water imbalance and caloric deficit, ranging downward to possible starvation levels. This will be alleviated over protracted survival periods only to the extent that nutrients can be foraged from the surrounding terrain. For this reason, such items as desalting kits, fishhooks, and hunting gear are included in emergency packs to assist the more fortunate and resourceful airmen in "living off the land."

Where the environment is completely nonproductive, the survival-energy potential is limited to the water and food substances that can be carried individually. Special survival-type food packets have been produced specifically to maintain physical condition and morale over the longest possible periods. These are all concentrated foods designed to occupy minimal space in survival packets. The food items are tested for their ability to sustain life in different climatic conditions and for general storage stability which must exceed 2 years.

The Feeding of Patients

Flight-feeding facilities in the Air Force are responsible for the preparation and handling of regular flight meals for hospital patients aboard aeromedical evacuation aircraft in the continental United States and overseas. The aeromedical evacuation control officer, or the aeromedical evacuation coordinating officer, as defined in AFR 164–1, is responsible for procuring required modified diet items and/or meals from the hospital food service. Guidance for the ordering and preparation of modified diet in-flight meals is in chapter 21, AFM 160–8, 1 June 1968.

REFERENCES

The reader should insure the currency of listed references.

AFM 146–1, *Food Service Management.*

AFM 146–2, *Flight Feeding.*

AFM 146–7, *Instructor's Guide—Sanitary Techniques and Personal Hygiene.*

AFM 160–8, *Applied Clinical Nutrition.*

AFM 161–6, *Medical Aspects of Food Service.*

AFR 160–95, *Nutrition.*

MIL–F–3764C, 17 December 65, *"Military Specifications, Food Packet, Individual, In-Flight."*

Chapter 14

AVIATION PATHOLOGY

In the investigation of aircraft accidents, the contributions of the Medical Member of the Aircraft Accident Investigating Board, in association with the Pathologist, are firmly established as a significant part of the total inquiry. The close cooperation of these medical specialists is recognized as essential for thorough evaluation of human factors in terms of physical, physiologic, and psychologic processes and their role in the disruption of the man-aircraft unit. Medical findings have, in some instances, ruled out "pilot error" or "undetermined" as the cause of an accident when a careful autopsy has proved the existence of some specific physical ailment, such as coronary artery disease. Thorough medical analyses ultimately bring about improvement in pilot selection processes and enhancement of personnel safety features of aircraft and spacecraft.

Strong impetus was given to the application of pathology to aircraft accident investigation in 1955, when the Department of Defense issued a directive establishing the Joint Committee on Aviation Pathology (JCAP), composed of representatives from the military medical services of the United States, Great Britain, and Canada. The Armed Forces Institute of Pathology (AFIP), Washington, DC, is JCAP Headquarters and has been further designated as the central coordinating facility for investigation of the pathology of aircraft accident fatalities. The Aerospace Pathology Branch has the prime responsibility for this mission and utilizes the full consultant, histopathologic, and toxicologic facilities of the AFIP in analyzing both military and civilian cases collected.

Pathology Support

The authority for providing a pathologist at the scene of an aircraft accident is AFR 160-109. Pathology support from the Military Consultant Centers is authorized and outlined in AFR 160-51. Most of the toxicologic analyses (*i.e.*, carbon monoxide, lactic acid, and alcohol) are to be performed by the designated Class A Laboratories per AFR 160-109, with additional support provided as required by the Epidemiological Laboratory at Lackland AFB, by the AFIP, and by other histopathology centers. Unusual or difficult analyses, such as those involving drugs, are referred directly to the AFIP.

With the active participation of more consultants, the number of Air Force pathologists with experience in aircraft accident investigation will increase at an appreciable rate. A Flight Surgeon or a Flight Medical Officer may be exposed to only a few accidents during his entire tour of duty in the Air Force, but a Pathologist at a Military Consultant Center will often participate in many investigations, at several bases, in his area during a 2 or 3-year tour. By approaching each accident investigation as a team, the Flight Surgeon or Flight Medical Officer and the Pathologist can pool their experiences and more effectively discharge their responsibilities.

Basic Procedures

Experience has proven that each investigation varies slightly from the next. There are, however, a few basic procedures which will aid the Flight Surgeon in carrying out an efficient and thorough investigation. These are discussed below. Problems not covered in this discussion may be referred, day or night, to the Officer-On-Call at the

Aerospace Pathology Branch, AFIP, Washington, DC.

First Step:

This is the most important phase of every aircraft accident investigation. It requires the medical officer to obtain immediate transportation to the crash site and exercise authority to prevent disturbance of the fatally injured victims *in any way* until after they and the scene of the accident have been thoroughly documented in photographs, preferably in color. While this requirement should not be interpreted as preventing firefighters from determining the presence of signs of life, the fact remains that valuable evidence is frequently distorted or destroyed by well-meant rescue operations. Photographs will, at least, partially preserve these details for later analyses by pathologists and flight surgeons.

The rapid reaction time required for this initial phase, obviously, demands a prearranged disaster plan. To provide medical coverage for a crash site distant from the base, it is strongly urged that each Flight Surgeon establish arrangements for immediate air transportation as an integral part of the disaster program.

A compact flyaway kit should be available for unscheduled emergencies. In addition to personal gear, other useful equipment should include a 35 mm camera, color film, flash unit, tags, waterproof marking pen, a 50-foot steel tape, compass, paper, pencils, rubber bands, and polyethylene bags.

Second Step:

When the general wreckage distribution has been photographed from all angles, and the casualties have been photographed and examined in their original positions, the remains should be tagged with an identifying number and moved, and the original location then marked by an identically numbered tag or stake. At the time of removal of the remains, it is important to note all environmental features which may have contributed to the injury pattern, such as seat belt failure or possible traumatizing control knobs. It is imperative that suspected evidence be documented by photographs.

After the casualties have been moved to the mortuary and refrigerated, pending the arrival of the pathologist, the numbers should be plotted on a scale diagram indicating the wreckage distribution. Photos of the flight path and aerial views of the crash site are frequently helpful in determining force vectors producing certain injuries and in ascertaining specific traumatic agents in the cockpit or cabin environment.

Although examination of the site is an essential part of the pathologist's examination, the medical officer should examine the wreckage as early as possible for trace evidence. The canopy or tail surfaces may reveal fabric, tissue smudges, or blood which will enable the correlation of injuries with the time and place of occurrence, such as in the cockpit, in the air, or on the ground. Scrapings of such materials can usually be identified under a microscope.

Additional significant data may often be obtained from careful examination and photographic documentation of the casualty's personal equipment to ascertain its condition and functional status. Tears of flying clothing and direction of blood flow from lacerations may be integrated with injuries found at autopsy. Marks and other damage to the helmet and oxygen equipment must be evaluated. Every aspect of ejection failure must be checked, and an attempt at reconstruction of the sequence of events of the ejection must be made.

Because of his intimate knowledge of operational activities, the Flight Surgeon should be able to provide the pathologist with details of personal equipment, ejection seats, and cockpit configurations with which the latter may not be familiar.

Third Step:

AFM 168-4 requires that an autopsy be performed when death occurs while the person is serving as an aircrew member in a military aircraft. The Base Commander may authorize an autopsy when the accident occurs within his jurisdiction.

However, when the accident occurs outside the base perimeter, the local coroner or medical examiner exercises legal authority over the accident site and the remains. Depending on local statutes, permission must be obtained from the coroner or medical examiner before the casualty is removed from the crash site and before an autopsy may be performed.

If the local legally constituted authority is unwilling or unable to make such an authorization, permission must be sought from the next of kin. Merely transporting the remains to a military base does not permit the Base Commander to authorize the autopsy.

In some instances, the coroner or medical examiner may insist on performing the post mortem examination himself. An interested party, such as a medical officer, is usually welcome as an observer.

In the same general area of legal requirements is the necessity to establish positive identification of the remains. Such identification may be established by reference to the personal belongings that are carefully tagged and transported with each victim, by jewelry, metal identification tags, fingerprints, footprints, and dental records, and, occassionally, by blood type, hair type, or comparison of clinical and post mortem X-rays. Local law enforcement agencies are usually unskilled in this work, but can obtain assistance through the Base Mortuary Officer (AFM 143-1). If necessary, the services of the Federal Bureau of Investigation may be requested.

Although some of these legal requirements may lie within the province of the pathologist, the Medical Member of the Accident Investigating Board, who is aware of these requirements, can expedite the investigation by proper preplanning.

Fourth Step:

At the mortuary facility, it is desirable that the casualty be photographed again, both clothed and unclothed, from all angles, and preferably in color. Additional photographs of major lesions should be taken as indicated during the course of the autopsy.

It is also desirable that X-rays of the entire body be taken, using fixed radiographic facilities. This is most conveniently accomplished by scheduling such procedures after normal hospital duty hours. Occult fractures and foreign bodies are thus easily detected prior to autopsy, and the poor quality and artefacts of portable equipment can be avoided.

Fifth Step:

To be of value, the pathologic investigation must be approached from the forensic viewpoint. Trauma should be related to the causative agent. The medical officer should recognize that the "case history" includes personal and family backgrounds, interpersonal relationships, occupational stresses, and the history of the last flight. The unique relationship that existed between the Flight Surgeon and the flying personnel will provide the pathologist with much of the information he seeks. Medical and personnel records should be thoroughly reviewed for additional data before the autopsy.

Post Mortem Examination:

On rare occasions, the Flight Surgeon may find himself without assistance to perform an autopsy. To be prepared for such a contingency, the Flight Surgeon must familiarize himself with the essential techniques in AFM 160-19.

When an Air Force pathologist is not available, it may be desirable to seek the assistance of a civilian consultant or a Navy or Army pathologist. In all instances, specimens and reports should be submitted per AFR 160-109.

FACTORS FOR CONSIDERATION

Experience in evaluating Aviation Pathology cases has yielded three broad categories of data that encompass most of the pathological information, namely, environmental conditions, traumatic aspects, and pre-existing disease.

Environmental Factors

Altitude:

a. *Hypoxia:*

One of the most important and least readily solved problems confronting aircraft accident investigators is the detection of acute ante-mortem hypoxia. Histopathologic changes are of little or no value in its diagnosis, and chemical tests are reliable in only a low percentage of cases.

Through the joint efforts of the RCAF Institute of Aviation Medicine and the USAF School of Aeroscape Medicine, a colorimetric test on frozen, unfixed, central nervous system tissue obtained at autopsy, was devised to measure the lactic acid concentration. This intermediate metabolic product accumulates in significant quantities in neural tissues when glycogen levels in the blood increase as a response to stress. A decrease in aerobic metabolism, as might occur under hypoxic conditions, also causes the lactic acid level to rise.

Lactic acid concentrations over 200 mg% in gray matter are indicative of stress, although the elevated level does not differentiate the cause of the stress. Therefore, a variety of conditions—such as lack of oxygen attributed to altitude, drowning or strangulation, ingestion of certain drugs, and shock—may produce an elevated lactic acid value in the brain or spinal cord. It is worthwhile to note that, if an individual survives an injury long enough to receive medical treatment, intravenous administration of dextrose and water or of citrated blood may produce misleading elevated lactic acid levels.

Among 1,219 aircraft accident cases in which this test was routinely performed at the AFIP, there were 141 instances in which a value over 200 mg% was obtained. In nine cases, there was definite evidence that the elevation was due to altitude hypoxia; the available history supported the chemical findings. In 66 cases, there was a history of the casualty's brief survival in a state of clinical shock, following the accident. Four cases were attributed to altitude, strangulation, or hyperventilation; 11 cases to suffocation; and 26 cases to drowning. In 16 cases, the cause of the elevated values could not be determined, and in nine others, no history was available.

On the other hand, it must be admitted that there are a certain number of cases in which the available facts appear to indicate a stressful circumstance, but in which the lactic acid is not significantly elevated. Thus, it can be seen that this test is reliable only when central nervous system lactic acid is significantly elevated (above 200 mg%), and this elevation correlates positively with the history of the accident.

b. *Decompression Sickness:*

The post mortem findings in these cases are thought to be due, at least in part, to fat embolism secondary to a decrease in ambient barometric pressure. Intravascular fat has been found in the lungs, brain, and kidney in some of these cases, and areas of cerebral ischemic necrosis have been noted to be indistinguishable from those caused by aero-embolism.

The pathogenesis of this condition is not clearly defined, but it has been postulated as follows: Adipose tissue contains a supersaturation of nitrogen; upon decompression, the dissolved nitrogen forms expanding bubbles which rupture the cell membranes and release both fat and gas into the vascular system.

This simple explanation of embolism may actually reflect a more fundamental change in the tissues. The problems of decompression sickness and the causes of its various manifestations deserve considerably more fundamental investigation.

Speed:

a. *Spatial Disorientation.* Spatial disorientation is difficult to prove because, as far as is known at present, there is no demonstrable pathologic lesion. It is significant to note, however, that inner ears are seldom examined in suspected cases, although their removal should be routine in every aircraft accident fatality. The occult nature of spatial disorientation taxes the ingenuity of all aircraft accident investigators.

b. *Windblast.* In an attempt to prevent "windblast" injuries resulting from high-speed ejections, experiments have been conducted using primates as subjects on rocket sleds at speeds exceeding Mach 1. The exposed skin surfaces showed a number of changes, including separation of the superficial epidermis into a distinct layer, compression of the remaining epidermis into a thin, leathery structure, epilation, and focal hemorrhages. The windblast and high dynamic air pressure resulted in a thermal elevation to about 300° F. As a result of this and other studies, the designing of protective clothing and equipment has played a major role in the prevention of injuries to flying personnel, the most advanced development of which is the closed-environment, self-sustaining escape capsule for high-performance aircraft.

Toxins:

a. *Carbon Monoxide:*

Much work has been devoted to the environmental problem of toxins, especially carbon monoxide. Although carbon monoxide has been one of the more commonly incriminated toxins associated with aircraft accidents, a careful study reveals that significant carboxyhemoglobin values are usually associated with viability and a history of fire, either in flight or following ground impact. Therefore, the practical value of a post mortem carbon monoxide level lies in its assistance in establishing the sequence of events—*i.e.*, whether the person was alive or dead at the time the fire ensued.

An aircraft accident investigation routinely includes the analysis of unfixed tissues for carbon monoxide. If blood is not available, the laboratory can utilize aqueous extracts from blood-containing organs. The extracts are analyzed in the same manner as whole blood, preferably by gas chromatography, and the results are reported as percent carboxyhemoglobin saturation. Levels less than 10% are considered insignificant because heavy smokers may attain values as high as 8 or 9%.

Of 1,904 cases analyzed by this method at the AFIP, 198 demonstrated an elevation (over 10% carbon monoxide saturation), and all of these correlated with a history of fire. The magnitude of carboxyhemoglobin concentration does not, necessarily, reflect the length of exposure to the gas because the tissue level attained depends upon the integrity of the individual's circulatory and respiratory systems, on the concentration of carbon monoxide in the products of combustion, and on the availability of ambient oxygen to dilute the carbon monoxide.

b. *Alcohol:*

Unfixed tissues are also routinely examined for the presence of ethanol, because of its well-known depressant effect and the fact that many of the casualties show varying degrees of fatty metamorphosis of the liver. Positive results for alcohol, however, are rare among military personnel.

Putrefactions may produce artefactual ethanol concentrations in some instances, usually detected together with acetone and acetaldehyde by gas chromatography. A delay of as little as 8 hours before refrigeration of urine, kidney, brain, or other parenchymatous organs may result in a misleading positive alcohol test. Alcohol is also a common constituent of embalming fluid.

c. *Drugs.* When clinical evidence indicates that a search for drugs might be worthwhile, this analysis becomes a part of the toxicologic evaluation. Practically no medication can be considered completely harmless to personnel flying high-performance aircraft under operational stresses. Antihistamines and ataractics have been implicated in a few accidents as contributing causes. Liver, bile, stomach contents, kidney, and urine are useful for this type of analysis. Because of the complexity of the method and the manhours involved, drug analysis should not be requested routinely.

Temperature. In spite of well-regulated air conditioning systems, the present-day pilot must be prepared to encounter an extreme temperature range within a single flight. The severe cold experienced at high altitudes has been sufficient to produce serious thermal injuries in ejection cases. Therefore, for survival, it is necessary that flying personnel be furnished with adequate personal equipment. It is even more important that fliers be trained in the use of this equipment and that they apply their training to practice. Aircraft accident investigators should determine what effect the personal and survival equipment has had on the fates of both the victims and survivors, and they should not hesitate to make pertinent recommendations.

In addition to the above, other environmental factors that should be considered are the effects of noise, vibration, and stress.

Traumatic Factors

The second broad group of pathologic changes studied in aircraft accident fatalities focuses on traumatic lesions. In many instances, these injuries appear so extensive and, obviously, the immediate cause of death that even medical personnel unfamiliar with Aviation Pathology techniques raise the question as to why an autopsy should be performed when the cause of death is so apparent.

In aircraft accident investigations, however, it is insufficient to state the immediate cause of death, such as crushed chest, fractured skull, or injuries, multiple, extreme. To achieve the goals stated at the beginning of this chapter, it is necessary to pinpoint the objects and/or forces producing the injuries that resulted in the lethal lesions. *For example,* if the cause of the accident is clearly established as mechanical failure of the aircraft, the investigator should devote his efforts primarily to determining how the crew member sustained his specific injuries by relating them to known mechanisms of the accident, such as angle of descent, force vectors at impact, and the physical nature of the traumatizing agent. From this integration, aerospace architects and engineers may learn how to improve their designs to prevent the recurrence of similar injuries.

On the other hand, if the cause of the accident is unknown, the prosector should learn all the available facts about the circumstances of the accident before he begins the post mortem examination. Without this background, he may waste much time and effort in irrelevant work. The autopsy should then be conducted in a careful and meticulous manner, employing an inductive reasoning approach, and using as many adjunctive studies as possible, such as X-rays and chemical and bacteriological studies.

The correct interpretation of certain pathologic findings will frequently lead to invaluable clues in unraveling the sequence of trauma. *For example,* when examining the heart and lungs, it is important to determine whether lacerations were actually compression ruptures or were made by fractured ribs, and if the latter, by which ones. If there was a laceration of the aorta, it should be determined whether it was produced by a fractured bone or was the result of impact deceleration, each of which shows characteristic lesions. (Ruptures of the aorta in the arch or just distal to the left subclavian artery are characteristic deceleration injuries.)

In analyzing a laceration of the liver, it would be helpful to know if it was due to rib fractures or to a crushing injury compressing the liver against the vertebral column. The question of viability during a fire can be resolved by demonstrating soot, either grossly or microscopically, within the respiratory tract, indicating that the subject inhaled smoke and, thus, was alive in the presence of a fire.

It is well to remember that heat alone can produce epidural hemorrhage and fractures of the skull and extremities.

Preexisting Disease

Coronary atherosclerosis is probably the most frequent preexisting disease among fliers of all ages, and its pathophysiology offers much room for speculation. A coronary attack in the pilot of a single-place aircraft could well result in another unexplained accident. (Predictions of the importance of coronary disease among pilots were made by Benson and White in 1937 and 1940.) Although many of the coronary arteries of deceased pilots show moderate to marked coronary sclerosis, the significance of such findings must be interpreted with caution. The failure of histology to parallel physiology is well known.

Other types of preexisting disease have been responsible for sudden incapacitation of a crewmember with or without a resultant accident. Nelson and Haymaker have described three cases of sudden incapacitation caused by a colloid cyst of the third ventricle. An astrocytoma was responsible for the first onset of unconsciousness in one pilot, which would have resulted in an accident had a copilot not been present. Sudden crew incapacitation has occurred as the result of sickle cell anemia. Certainly, any disease that can produce sudden death at ground level can similarly produce sudden death at altitude, and can best be detected by a skilled pathologist.

SUBMISSION OF SPECIMENS

Toxicologic Analysis

Routine Analyses: Routine analyses include determinations of carboxyhemoglobin, lactic acid, and ethanol. The optimum tissue quantities include 50 ml blood; all urine; 250 gm lung; 500 gm liver; ½ of each kidney; 1 cerebral hemisphere or, if brain is not available, 6 inches of spinal cord.

Lesser quantities may be submitted if they are the maximum available but, in that event, the spleen, bone marrow, and skeletal muscle should be included to assure sufficient blood-containing tissues for carboxyhemoglobin determination. Lactic acid levels are only of significance when determined from relatively untraumatized central nervous system tissue.

Organs for toxicologic analysis should be heat-sealed individually in the bottom half of standard-issue plastic bags. An identifying card marked with the casualty's name and rank, autopsy number, date of accident, submitting base, and type of tissue should be sealed into the upper half of each bag. Liquids, such as blood and urine, are most conveniently transported in latex bags (condoms) tied with a firm knot, inclosed within a second firmly tied latex bag, and labeled with an attached tag. Glass jars and small, capped tubes should not be used for shipping frozen specimens because of their tendency to shatter when the contents are frozen.

It is essential that specimens for chemical analysis be kept free of contamination. Tissues removed after embalming are unsatisfactory, and traces of formalin fixative will interfere with the analysis. *Fresh tissue must not be transmitted to the laboratory in the same package with fixed specimens under any circumstances.*

Specimens must be frozen by any method available (usually dry ice) as soon as possible after the accident, to prevent putrefaction. A brief period of refrigeration is acceptable only if freezing facilities are not available. Without thawing, the tissues should be packed for shipment in an insulated cardboard container with sufficient dry ice to maintain the frozen state for 48 hours. If only a metal, vacuum-type container is available, it must be punctured to prevent accumulation of CO_2 under pressure and possible explosion. A copy of DD Form 1322, "Aircraft Accident Autopsy Report," sealed in a separate plastic bag, should also be inclosed for identification and information purposes.

The packaged specimens should be addressed to the Chief, Clinical Laboratory Service of the regional Class A Laboratory (*not* to the Military Consultant Center unless these facilities coincide), and labeled as follows: "FRAGILE, RUSH, FROZEN SPECIMEN FOR TOXICOLOGIC EXAMINATION (AIRCRAFT ACCIDENT). DRY ICE ADDED AT ____ HOURS; RE-ICE IF NOT DELIVERED WITHIN 36 HOURS." (See AFR 160-109.)

Tissue shipments of this nature should be transmitted by air freight or by military carrier, and the addressee should be notified of the carrier, flight number, estimated time of arrival, and bill of lading number by the fastest means possible.

Special Studies:

When special toxicological examination is required, specimens should be transmitted directly to the AFIP, inclosing a copy of DD Form 1322 and any data pertinent to the tests requested. All specimens should be prepared for shipment in the same manner as those destined for the Class A Laboratory, and similar advance notification provided the Director of AFIP.

Such investigations might include an analysis of unlabeled medications or tissue for drugs (500 gm liver; 250 gm lung; ½ each kidney; 50 ml blood; all urine; all bile; and all gastric contents are required). In suspected drownings, one complete lobe of each lung and at least ½ kidney will be submitted for diatom determination.

The laboratories will send written reports of both routine and special determinations to the investigating base. Assistance by phone may be obtained at any hour from the Aerospace Pathology Branch, AFIP.

Histopathologic Examination

Representative specimens from all organs should be fixed in 10% neutral formalin for 18 to 24 hours. Tissue slices should measure not more than 5 mm in thickness to permit thorough fixation.

After preliminary examination of the unfixed heart, including serial cross sectioning of the coronary arteries at 5 mm intervals, the entire heart should be immersed in formalin. Remaining portions of the brain and spinal cord should be thoroughly fixed in a similar manner. Because the brain requires several days for adequate formalin penetration, the heart may remain in fixative for a similar period. Specimens for histopathologic examination should *never* be frozen, either before or after fixation.

After adequate fixation, the specimens should be wrapped in cheesecloth moistened with formalin and heat sealed in plastic bags. These tissues, properly identified, may then be transmitted to the regional Class A Laboratory by the most practical means. They should be accompanied by a copy of DD Form 1322, along with any descriptions, X-rays, photographs, or other materials not forwarded previously. *Fixed tissues should not be transported in the same container with specimens for toxicological examination.*

When the histopathologic examination has been completed, a written report and case analysis will be returned to the investigating base, and the case materials, including autopsy report, accident report, slides and/or paraffin blocks or tissue, will be forwarded *in toto* to the AFIP for review, coding, filing or further distribution.

REPORTS REQUIRED

For each casualty, the Medical Member of the Accident Investigating Board will complete the Aircraft Accident Autopsy Report, DD Form 1322, or its equivalent, in cooperation with the pathologist. A copy of this form will accompany all shipments of materials to the Class A Laboratory or the AFIP for purposes of identification and information.

Supplemental materials include photographs of the crash site and wreckage, victims *in situ* and at autopsy, and interesting or unusual lesions. A diagram or labeled photograph of the wreckage distribution and body positions is a useful adjunct to a detailed narrative of the accident sequence.

Upon conclusion of the investigation, the Flight Surgeon should forward to the Class A Laboratory and the AFIP, a summary of the Board's findings, together with his analysis of the human factors data and personal recommendations.

Additional reports required under AFR 127-4 are not to be submitted with the autopsy material unless specifically requested.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, Harry G., *Aerospace Medicine,* The Williams and Wilkins Co., Baltimore (1961).

Dominguez, Abel M., *Problems of Carbon Monoxide in Fires,* Journal of Forensic Sciences, 7:379-393 (1962).

Dominguez, Abel M., *Significance of Elevated Lactic Acid in the Postmortem Brain,* Aerospace Medicine, 31:897-900 (1960).

Mason, J. K., *Aviation Accident Pathology,* Butterworths, London (1962).

AFM 143-1, *Mortuary Affairs.*

AFM 160-19, *Autopsy Manual.*

AFM 168–4, *Administration of Medical Activities.*

AFR 127–4, *Investigating and Reporting USAF Accidents/Incidents.*

AFR 160–109, *Medical Investigation of Aircraft Accident Fatalities.*

AFR 160–127, *Joint Committee on Aviation Pathology.*

Chapter 15

THE FLIGHT SURGEON'S ROLE IN FLIGHT SAFETY

The Flight Surgeon's role in flight safety is of paramount importance. Indeed, the Flight Surgeon's rating and flying status are justified, to a great degree, by his contribution to flight safety, the end product of many of his endeavors.

The following facts illustrate the importance of promoting aerospace safety in the Air Force. A review of mortality rates during 1964 and 1965 reveals that 73% of all deaths occurring in Air Force flying officers during that period were attributed to aircraft accidents. Other statistics indicate that, from January 1960 to 1 January 1966, 1,974 persons died in Air Force aircraft flight accidents. This also entailed the loss of 1,677 aircraft at an average annual cost of $376,474,000.

The Deputy Inspector General for Inspection and Safety defines "aerospace safety" as the conservation of our resources, whether men, money, or materiel, from the standpoint of increasing the over-all effectiveness and combat readiness of the Air Force. The Aerospace Safety Directorate of the Deputy Inspector General for Inspection and Safety is divided into three divisions: Flight Safety, Ground Safety, and Missile and Space Safety. This chapter will deal only with Flight Safety.

The Flight Surgeon's daily activities involve all phases of Flight Safety. For purposes of clarity, these phases are presented in this chapter under three major categories: *The Flying Safety Program, Standard Procedures in Aircraft Accidents*, and *Accident Investigation*. The last two are closely related to accident prevention which is the primary goal of flight safety. In the investigation of an aircraft accident, the factors that produced the accident are identified and evaluated, and recommendations as to ways and means for preventing recurrences are established. The Flight Surgeon evaluates the patterns of human injury to determine the effectiveness of personal protective, life support and emergency egress equipment. From this evaluation he makes recommendations for improvements and modifications of this equipment.

THE FLYING SAFETY PROGRAM

The role of the Flight Surgeon in flying safety has several aspects. His practice of flight medicine, his participation in flying activities, his support of the flying safety education program, and his contribution to research and development activities form the firm foundation of this role.

Flight Medicine

Medical Selection. Medical selection of applicants for aircrew training is one of the most effective flying safety measures available to the Flight Surgeon. When performing Class I physical examinations, he should realize the importance of a thorough and complete evaluation of each applicant and the implications of his decision that the man is physically qualified. Errors of selection on his part could result in an accident during training or a costly elimination from a training program. The conscientious application of the exacting physical and psychological standards in AFM 160-1 has helped to keep human factor accidents and hazards to a minimum.

Annual Physical Examination. Physical qualifications for flying are monitored by the annual Class II physical examination and during individual medical attention provided by sick call visits. The high standards of medical selection and qualification have produced a very healthy population. This is reflected in the very low incidence of medical incapacitation as a cause of aircraft accidents.

Routine Medical Care. Providing prompt, personalized medical attention and care to the flier is an important responsibility of the Flight Surgeon. Maintaining the health and physical fitness of flying personnel has a direct relationship to flying safety and combat effectiveness. The Flight Surgeon must evaluate each disease and injury in terms of the impact that such conditions may impose on each flier's ability to perform safely and effectively. Aircrew confidence and respect for the Flight Surgeon are gained from the application of high professional medical standards. This confidence and respect pay off by the earlier reporting of disease and injury, with resultant early treatment and lower morbidity. Delays in seeking medical advice and/or a practice of self-treatment by fliers might otherwise result in situations fraught with hazard, particularly in the flying environment.

An early return to flying status is essential to maintain crew integrity and a low level of noneffectiveness. While such a practice fully supports commanders in meeting their operational commitments, it is imperative that full professional consideration be given to insure complete recovery from the disease or injury and the effect of medications. The stresses of flight can be unforgiving, especially when a person's physiology and ability to respond are compromised.

Medical Education and Training. Another important aspect of the Flying Safety Program is medical education and training. This role of the Flight Surgeon is assumed during formal and informal contacts with aircrew members. A contribution to expanding their knowledge of medical facts, health hints, and first aid may occur, *for example,* as a result of a presentation at a flying safety meeting, while conversing at lunch in the alert facility, while conducting the physical examinations, or in the course of performing flying activities. The following topics, which, generally, have been well received by the aircrews, are recommended for frequent presentation:

Basic concepts of hygiene and nutrition.

Types and effects of fatigue.

Effect of medication and dangers of self-medication.

Health aspects of smoking, obesity, and physical fitness.

Pharmacology of ethyl alcohol.

Personal preventive medicine measures.

Use of protective equipment. (The Flight Surgeon should illustrate this topic with actual case histories; *for example,* the protection boots and gloves afforded a flier who exited an aircraft on fire. Pictures can add emphasis.)

Flying Activities

The Flight Surgeon's flying and flightline activities represent one of his most productive areas of endeavor. By active participation in his unit's flying mission, the Flight Surgeon experiences the psychophysiologic stresses of the flying environment. This experience provides him with a valuable background for evaluating the reactions of aircrewmembers to the stresses of flying. In addition, it provides an opportunity to evaluate firsthand the crew discipline, use of personal and survival equipment, and hazardous conditions related to aviation.

Perhaps the most important and difficult task a Flight Surgeon faces is the establishment of rapport with the aircrews. "Professionalism" is a way of life to our aircrews, and a Flight Surgeon must demonstrate a professional approach to his aircrew duties to be accepted by the flight crews. By demonstrating medical proficiency in the flying environment, the Flight Surgeon strengthens the confidence of fliers in his medical ability and establishes the rapport that will bring them to his office when they have symptoms that may threaten their flying careers. This probably will be the Flight Surgeon's most important contribution to flying safety.

Flying Safety Participation

In the performance of flying safety activities, the Flight Surgeon should establish a close working relationship with the unit Flying Safety Officer. The Flying Safety Officer is a source of information on the technical aspects of flying safety and can pinpoint problem areas in which a medical input is required. The Flight Surgeon, on the other hand, should offer consultation and advice on matters pertaining to the physiology of flight, medical problems, and personal and survival equipment. Thus, the Flight Surgeon/Flying Safety Officer Team brings medical activities into direct alignment with the Flying Safety Program.

The Flight Surgeon should participate actively in unit flying safety meetings and have a role in planning them. Presentations and discussions need not be long and highly technical; ideally, Flight Surgeon participation should be brief, to the point, and presented in understandable terminology.

Topics for the meetings should be timely and pertinent to the flying mission. A suspense file should be kept, to insure the discussion of seasonal hazards before the fact. For instance, winter flying and survival hazards should be covered in the early fall. The unit flying mission should be closely monitored because special missions often dictate unscheduled coverage of unique medical hazards. Topics should be covered repeatedly, and, here again, a suspense file of topics is helpful. It requires an imaginative approach to present the same material again and again without boring the audience. Repetition is essential, however, because of the rotation of personnel and the necessity to assure that medical hazards are recognized and avoided.

Personal experience with the aircrew members is a prime source for interesting and timely topics. Background medical, flying, and accident experiences often dictate pertinent topics concerning the health and welfare of aircrews.

The Flying Safety Officer also should be a source of topics as he receives from the Directorate of Aerospace Safety, DIG/IS, Norton AFB, the bimonthly Kit for Flight, Ground, and Missile Safety Officers, containing information extracted from the entire Air Force accident/incident experience. "Notes to the Flight Surgeon," prepared by the Life Sciences Division, is also a part of this kit and is an important source of current aeromedical problems.

The publications, "Aerospace Safety" and "Aerospace Maintenance Safety" are also good references.

Research and Development Activities

A few flight surgeons will be assigned to primary Research and Development centers. Their primary duty in such assignments is related to the multiple facets of life sciences and life support. They endeavor to "fit the machine to the man." This requires the thorough application of medical knowledge to the design and engineering of the entire weapon system and covers every parameter of operation.

Research and Development (R&D) activities attempt to insure maximum efficiency and effectiveness of weapon systems and, in the case of mishap, to provide procedures and equipment that will permit emergency escape and survival of our most important resource, the trained aircrew member.

The role of the Flight Surgeon in aerospace R&D may be important when he generates requirements for R&D. He does this by recognizing and reporting materiel deficiencies. He may support the flying safety officer, the life support officer, or the aircrew member in submitting reports, such as AFTO Forms 29, "Unsatisfactory Report" (URs), Emergency Unsatisfactory Reports (EURs), reported on DD Forms 173, "Joint Messageform," and AFTO Forms 109, "Quality Control Deficiency Report" (QCDRs). R&D activity in response to these reports often results in design and quality deficiency corrections, new and modified equipment, or improved operational procedures. The Flight Surgeon, then, has the opportunity to evaluate the effectiveness and the crew acceptance of these results. This evaluation is important because equipment and procedures which are poorly accepted and applied may have adverse effects on flight safety and crew morale.

Operational Hazard Reports

The reporting of operational hazards is an effective tool in aircraft accident prevention. The Flight Surgeon may have opportunities to initiate or to support AF Forms 457, "Operational Hazard Report" (OHRs). These reports enable commanders to be immediately aware of, and to correct, dangerous conditions that could cause death or injury to personnel and loss of or damage to aircraft and property.

Aircraft Accident Investigation

Finally, the Flight Surgeon must investigate thoroughly each aircraft accident. This involves a retrospective investigation of all human and environmental factors that may cause an accident, and a determination of the effectiveness of egress systems and survival equipment. To support the investigation and findings, every scrap of evidence must be salvaged and all available information made a matter of record. Knowledge gained from such investigations plays an important role in accident prevention.

STANDARD PROCEDURES IN AIRCRAFT ACCIDENTS

Responsibility for Disaster Plans

It is the responsibility of the commander of each installation to publish a detailed Base Disaster Preparedness Operations Plan and to insure that the base is prepared to act promptly with appropriate measures to cope with potential or actual disaster situations. The Director of Base Medical Services (DBMS) is responsible for the Medical Annex to this Plan. Detailed information on planning and operations for disaster preparedness is in AFMs 160-37 and 355-1. The Flight Surgeon should be thoroughly familiar with the provisions of these manuals since he will exercise an early medical response to aircraft accidents and other disaster situations. The responses presented in this chapter are limited to those related to aircraft accidents.

Disaster Control Personnel

Personnel authorized to attend aircraft accident emergencies should be limited to the following three general groups:

Personnel required to participate in immediate aircraft accident operations (active participation);

Personnel required to perform related supporting services as circumstances may exist or develop (supporting participation); and

Personnel required to perform official duties in connection with such operations (administrative personnel).

Active participation is required by the following personnel:

Officer in charge of crash, firefighting, and rescue.

Crash, firefighting, and rescue crews.

Crash ambulance crews.

Designated medical personnel.

Special rescue crews (*e.g.*, rescue boat crews).

Supporting participation is provided by the following personnel as required:

Installation fire, maintenance and wrecker crews.

Provost Marshal, security, and law enforcement personnel.

Photographic personnel.

The entire base is alerted to provide administrative support. Examples of participants are: Public Relations or Information Officer; Chaplain; Base Legal Officer; and Explosive Ordnance Disposal Officer. The role of all of these personnel is usually detailed in the Base Disaster Preparedness Operations Plan (Base Oplan 355–).

Crash Alert and Notification Systems

Two crash alert and notification systems are generally used. These are the *primary* and *secondary crash alert nets*. The *primary* crash net is a direct wire, "hot line," intercommunication system normally installed between the control tower, the operations dispatcher desk, the crash fire station, and the crash ambulance station. The *secondary* crash alarm intercommunication net usually operates through the regular telephone exchange. It notifies, by established priority, all the necessary support organizations which, in turn, have their own disaster alert response plans.

The *Medical Crash Alert System* (MCAS) is generally a pyramidal one. This can vary according to the units' needs and capabilities. However, it should provide the following: *priority of notification; redundancy*, so that the absence of one person will not cause a break in alerting personnel; *flexibility*, to insure operational capability at all times and under all manning conditions, and *simplicity*, to avoid reference to complicated charts, etc. Practice is of paramount importance. Medical personnel should respond reflexively to emergencies. This can only be achieved by thorough initial training and repeated exercise of the Medical Crash Alert System.

A *crash message* is prepared at the earliest possible time by the operations and tower personnel. It is disseminated over the primary crash net to all members of the crash control team. Its purpose is to coordinate the crash control team efforts and to give advance warning of special conditions and/or hazards presented by the emergency or crash. The following information is included in the message: (1) Type of aircraft; (2) nature of emergency (*e.g.*, emergency landing or actual crash); (3) location of crash or landing runway in the case of emergency landing; (4) expected time of arrival; (5) number of occupants; (6) type of cargo (explosives, etc.); (7) the time before a "weapon" engulfed in flames will explode; and (8) such other information as is pertinent to the anticipated emergency operation.

Medical Support for Aircraft Disaster

The Director of Base Medical Services is responsible for all medical support in emergency and disaster situations. The medical facility must be prepared to organize disaster casualty control teams to insure maximum efficiency in the triage and treatment of casualties. The Chief of Aerospace Medicine must provide crash ambulances and trained crash ambulance teams on 24-hour standby alert. Provisions must be made for detection and decontamination of radiation and biologic hazards. The Flight Surgeon serves as the Crash Ambulance Team Chief and, as such, is the most important member of the Medical Crash Control Team.

The following are typical sequential procedures to be employed when the medical service implements a crash control exercise:

Initiate recall of medical personnel upon receipt of crash notification.

Dispatch crash ambulance teams to the scene.

Establish the Medical Command Post.

Prepare the hospital for emergency action.

Transport staff and supplies to the scene as requested by the Crash Ambulance Team Chief.

Initiate triage and the treatment of casualties as required.

Make a survey to determine radiation hazards.

Recommend exposure control and sampling procedures in the event a radiation hazard exists.

Identify and provide for the dead.

Investigate medical aspects of the crash.

Provide hospital medical care and evacuation of patients as necessary.

Procedures at a crash scene are fairly standard; however, because of the time, distance, navigation, and legal problems involved, it is mandatory to classify an accident under one of two categories: *on base* or *off base.*

On Base Accident Procedures:

Crash ambulance team departs immediately upon notification of emergency.

Crash ambulance proceeds directly to the scene (following all traffic and speed restrictions).

Crash ambulance obtains clearance from tower before crossing any runway. (This is done by radio or light signals from the tower. In the latter case, the ambulance should remain clear of the runway on "red" and proceed across on "green.")

Medical personnel will remain clear of the crash site until directed into the area by the Crash Firefighting and Rescue Chief.

(Two thousand feet is a minimum distance. They should avoid being downwind or downhill from the aircraft because of the fire hazard.) The medical team *will not enter:* the danger zone if explosives are a hazard; a burning wreck, until the fire is extinguished; a wreck where fire or explosion is likely, *unless cleared by the Fire Chief* and a lifesaving procedure requires their presence. In the latter case, rapid entry and exit are advisable. The reasons for this are twofold: (1) Inexperienced personnel may ignite a fire or trigger an explosion and (2) assuming a recovery role for which medical teams are untrained could result in unnecessary injury and death. (There have been cases where an entire medical team has been incapacitated by an explosion and fire at a crash scene.)

Off Base Accident Procedures: In general, bases have the responsibility for military aircraft disaster functions for half the distance between adjacent bases. (*Note: To Avoid Tragic Confusion, Know Your Area of Responsibility.*)

Standard maps are maintained at the control tower, base operations, fire and crash stations, security office, medical command post, and in crash ambulances. These maps cover a radius of 15 miles. They have numbered grids and superimposed compass-bearing lines to insure coordinated directions to the crash scene. The crash crews should be familiar with roads, bridges, paths, and other terrain features in the 15-mile area around the base. Map drills are an effective way to attain this proficiency.

Normally, when alerted for an off base crash, the crash ambulance will proceed to a designated convoy assembly point. A convoy is formed and led by the Crash Chief. Procedures are usually established for marking turns, etc., for follow-on vehicles. Occasionally, a crash ambulance will be dispatched to the off base scene, independent of the Crash Convoy. In this situation, the medical unit should know the location of the crash, route of travel, time of departure, and estimated time of return. This is especially important in foreign countries where ambulances are easily "lost."

Once off Government property, military personnel are subject to civil law. This also applies to the operation of emergency vehicles. Emergency vehicles are not to exceed legal speed or violate traffic rules. A clear understanding of the local laws should be established at each base.

In the event of aircraft fatalities, the remains come under the jurisdiction of the local coroner. It is extremely important to establish liaison with civil authorities and agree on procedures for handling this problem before a crash occurs. It is advisable to have a military legal representative advise medical personnel on any agreement discussed with civil authorities. AFR 160-109 emphasizes the importance of autopsies and establishes the responsibilities for performing autopsies on crew fatalities. Most civil authorities will welcome any assistance and cooperate fully if they understand the importance of such autopsies. *To repeat,* prior liaison is advised to assure cooperation and to avoid delays and confusion. If at all possible, military personnel should clear with the local coroner before removing a body to the military base. Undue delay is to be avoided.

Crash Site Procedures:

Obtain clearance from the Fire Chief to enter area.

Estimate the number and type of casualties. At the earliest opportunity, the Flight Surgeon must develop estimates and request additional medical help as required. Casualty estimates received in advance of the arrival of patients will better enable the medical staff to make necessary preparations. When all casualties in an accident are fatalities, the medical command post should be notified so that the entire medical unit is not held in an alert status unnecessarily.

Casualty Classification. Triage is the art of classification of multiple casualties by prognosis and by type and severity of injury. Triage, skillfully applied, is the best way to overcome and control confusion when large numbers of casualties are involved. Fundamentally, triage categories are based upon the physiologic threat posed by the injuries. The following classifications are used:

Class I. Minimal. No physiological threat exists and there is either no or scant loss of function. *Examples:* contusions, abrasions, lacerations; simple fractures of smaller bones; second degree burns of less than 10%; moderate anxiety states.

Class II. Immediate. Properly accomplished and brief lifesaving procedures are essential. *Examples:* mechanical respiratory hazards; hemorrhage at a quickly accessible site; severe extremity wounds; incomplete amputations; open fractures; crush wounds.

Class III. Delayed. A delay in management does not hazard life. *Examples:* moderate lacerations without extensive bleeding; second degree burns involving less than 30% and third degree burns less than 20%; closed fractures of principal bones; noncritical central nervous system injury.

Class IV. Expectant. Medical management requirements are complicated and time-consuming. *Examples:* second or third degree burns over 40%; abdominal injury with possible viscus damage; critical central nervous system injury; multiple severe injuries.

Medical Treatment at Crash Site. There are six immediate requirements in casualty care:

Maintain respiration.

Stop hemorrhage.

Immobilize all fractures (often this is extended to include soft tissue which has sustained massive trauma).

Prevent further infection—dress the wounds.

Never interfere with natural defenses.

Transport properly.

The Flight Surgeon should be able to accomplish quickly and effectively the procedures necessary to manage these requirements. His primary responsibilities are accurate diagnosis, rapid triage, and the efficient supervision of medical and paramedical personnel.

Initial treatment is performed "on the spot" if conditions permit; *i.e.,* splints, tourniquets, etc., are usually applied where the casualty lies, unless a fire hazard makes rapid evacuation of casualties necessary.

DD Form 1380, "U. S. Field Medical Card" (see AFM 168-4), is filled out at the time of triage. The diagnosis and type and time of treatment are necessary entries. Completion of this form will readily identify the person who has received initial treatment and thus, prevent overtreatment.

Casualty Holding Area (CHA). With large numbers of patients a considerable delay in evacuation can be expected, and many casualties will have to be held at the site. The Medical Team Chief should select a Casualty Holding Area to which casualties can be moved after initial treatment, and have metal standards and flags erected as markers for placing the casualties by type of injury. When casualties have been grouped according to the casualty classification, the medical personnel will direct stretcher-bearers to the specified area in the Casualty Holding Area. This orderly movement will permit more effective use of supplies and skills of medical personnel as well as simplify casualty surveillance.

The Casualty Holding Area should be located far enough from the crash to insure safety in case of fire or other potential hazards, but close enough to minimize litter portage. It should be located close to the access road, but out of direct line of traffic. (See figure 15-1(A).)

On selecting the site, the Medical Team Chief should insure that the ambulance driver unloads the medical supplies and erects the casualty classification standards. It frequently happens that, during Operational Readiness Inspections (ORIs), an ambulance driver will evacuate a load of patients and take all the available medical supplies with him. Therefore, the unloading of medical supplies at the holding point should be a checklist item. If a Disaster/Casualty Control Team is called in by the Medical Crash Team Chief, its members can concentrate their efforts in definitive care in the holding area. Also, as the workload shifts, the Medical Chief can better control the shift of medical personnel back to the hospital.

The Casualty Holding Area concept is very flexible and can be either omitted entirely or expanded, depending on the change in number of casualties, terrain, weather conditions, etc. *For instance,* with a crash on a small base, the Dispensary might become the Casualty Holding Area, while in a remote area, the Casualty Holding Area at the scene might have to provide definitive care for hours.

A crash ambulance should remain at the crash scene until the area is declared safe by the Firefighting/Rescue Chief and all firefighting/rescue personnel have left the area.

All uninjured personnel involved in the crash must be taken to the medical facility for observation. Further, they must receive an aeromedical evaluation and clearance by the Flight Surgeon prior to return to flying.

Crash Ambulance Team and Equipment:

Personnel. The Crash Ambulance Team Chief should be a Flight Surgeon. If it is after duty hours, the Medical Officer of the Day will be the team chief until the Flight Surgeon reaches the scene and takes charge. At least one first aid man, preferably an aeromedical technician who can also act as a driver, is required; also, a licensed ambulance driver who has some skill in first aid, is desirable.

Litter Bearer Requirements. For short carries over good terrain, one litter requires only two bearers. Up to a mile of unimproved terrain requires four bearers per litter. For anything over a mile or in difficult terrain, six bearers per litter will be required for sustained travel.

Litter Bearer Pool. Trained medical corpsmen should not be used as litter bearers in mass casualty situations. A manpower pool should be established at the perimeter of triage/initial care area. When initial treatment has been accomplished, the Crash Ambulance Team Chief should call in litter bearers who will move patients to the Casualty Holding Area. This prevents a waste of trained personnel and further injury to casualties by untrained persons. The use of a bullhorn is a valuable aid in directing this operation.

Crash Ambulance Equipment. Equipment for crash ambulances should consist of the following:

Standard maps with suitable grid or coordinate systems. Additional local or county maps that indicate trails and small roadways can be helpful, if available.

Basic equipment (litters, straps, splints) to care for at least four casualties. Blankets and extra material to construct more litters and cover at least 12 casualties.

A Crash Ambulance Kit and a Flight Surgeon's Kit. These are not standardized because of differences in physician preferences or the unique requirements of the area. However, they should contain medical equipment for emergency lifesaving procedures for 20 casualties and for the definitive care of 12 casualties.

Approved Resuscitator.

Supply of DD Forms 1380.

Human Remains Pouches.

Communication Equipment:

A two-way radio, capable of maintaining communication with the Medical Command Post, the Control Tower, and the Firefighting/Rescue Chief, is required.

A battery-powered bullhorn is desirable to enable the Crash Ambulance Team Chief to direct the Casualty Control operation over the noise and confusion at the crash scene.

Personal Equipment:

Hard Hats, color-coded to identify the Team Chief and the medical team, are an aid in establishing order at the crash scene.

Lanterns or Head Lamps that attach to the Hard Hats are essential for night operations.

Personal equipment for inhalation and ingestion protection against radiation should be provided. Boots, gloves, and coveralls, secured with masking tape, will provide adequate protection against gross external contamination.

Ample environmental protection

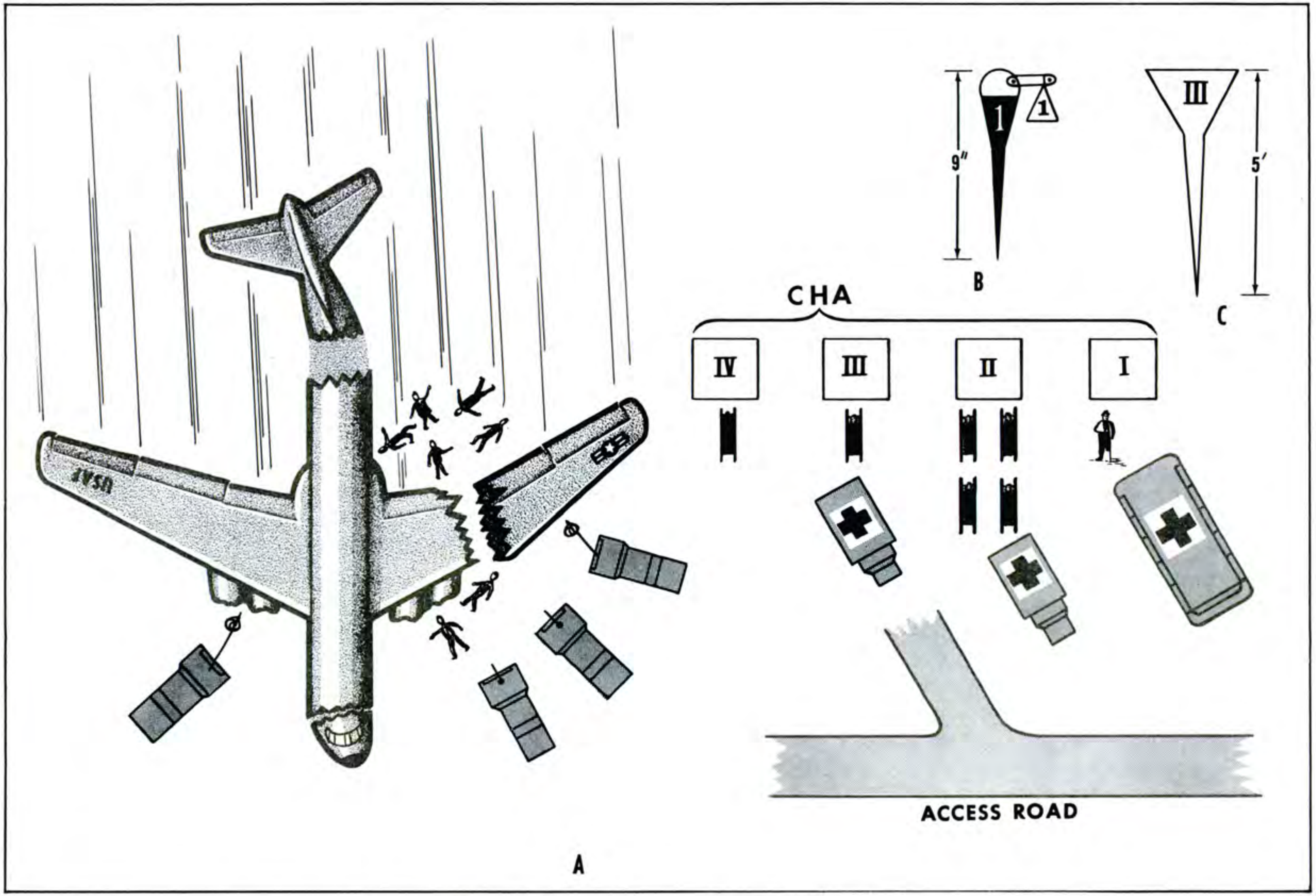


Figure 15–1. Accident Scene Schematic Showing the Casualty Holding Area Concept.

designed to meet the hazards of the local climate and terrain should be provided. (*To cite one case,* a crash ambulance team responding to a crash at one of our northern bases, was incapacitated by the unexpected nighttime cold.)

Miscellaneous Items. Many flight surgeons have devised miscellaneous items of equipment to meet local needs. These are fabricated at base shops at little cost. The following are recommended items of equipment:

Body Position and Identification Pins and Tags. (See figure 15–1(B).) These (steel) pins have safety-pinned tags with the same number *stamped* on both. The pin is easily inserted into hard ground to mark a position. The tag is pinned to the body, an object, or placed in a container. The numbers are stamped on to prevent loss of number by fire or smudging by water, mud, etc.

Casualty Classification Standards. (See figure 15–1(C).) These standards are color-coded by casualty type and placed in the Casualty Holding Area in a way that will insure correct grouping of casualties. This procedure avoids confusion and enables the Crash Ambulance Team Chief to merely direct litter bearers to a designated "standard" instead of having to give detailed directions.

Other miscellaneous items that have served a useful purpose include a crowbar, chain cutter, shovel, pickax, and hammer.

Accident Investigation Aspects of Crash Control Operations. The primary interest of the rescue team is, of course, preservation of life; however, the importance of the subsequent investigation must not be forgotten. The Flight Surgeon must carry out the following procedures when conducting crash control operations:

Maintain the accident scene as near to its original state as possible. This can be accomplished best by the use of body position identification pins (stakes) before moving casualties and bodies.

Photograph all bodies prior to movement, if feasible.

Make critical observations (photographs, if possible) of egress, personal, and survival equipment before anything is disturbed.

Identify body before removal, if possible—*i.e.,* look for all personal effects, dog tags, and papers in the immediate vicinity before moving a body. Examine the area covered by an incinerated body after its removal. Place remains and any possible identifying objects in Remains Pouch; also put DD Form 1380 inside the Pouch.

Methods of Remains Identification:

Position in aircraft—*i.e.,* pilot's or copilot's seat, etc.

Laundry marks—usually consist of initials and last four digits of serial number. (Look on underclothes, under belt, on a burned body.)

Personal effects.

Parachute number (not reliable on large aircraft). (Check at base personal equipment shop for issue record.)

Insignia, especially grade and rating.

Body marks, deformities, and tattoos (cross-check SF 88).

Fingerprints.

Footprints.

Body size.

Blood type and subtype.

Shoe and clothing sizes.

Dental identification. (This is a reliable method when performed by a qualified dental officer.)

Responsibility for Identification. The Mortuary Affairs Officer is responsible for the identification of human remains. He, however, will rely on the Flight Surgeon in many cases. In the event that all local resources have been exhausted and identity cannot be made, HQ AFLC, Wright-Patterson AFB, Ohio, will provide the services of Mortuary Affairs Identification Specialists on a 24-hour basis.

Autopsy

AFR 160–109 states the purpose, scope, responsibility, and procedures for autopsy. In general, autopsies will be performed on all crew member fatalities. In addition, autopsies will be performed on passenger fatalities when, in the opinion of the medical officer, such autopsies will yield information having a bearing on the cause of accident, mechanism of injury, or design of protective measures.

Military personnel will cooperate with the local coroner, to the extent possible, without jeopardizing national security or the performance of the military mission. This relationship should be preplanned with the assistance of the base legal officer.

ACCIDENT INVESTIGATION

Role of the Flight Surgeon

Under the provisions of AFR 127-4, an Aircraft Accident/Incident Investigating Board is established at each base, wing, or higher command to investigate and properly report Air Force accidents and incidents. A Flight Surgeon or Flight Medical Officer is designated as one of the primary voting members of each Board, and is responsible for the Life Sciences portion of the investigation (see AFM 127-2). He is uniquely suited to this investigative role because of his background in science and medicine which has developed his ability as a critical observer.

Investigation entails primarily the observation of facts and the reduction of these facts to a logical pattern, thus forming the basis for a scientific judgment. The Accident Investigating Board must rely on the Flight Surgeon for qualified opinions on psychophysiologic factors and their effect on the judgment of the pilot.

The Flight Surgeon, confronted with an aircraft accident investigation, faces a difficult and challenging diagnostic task. He must determine the human or environmental factors that contributed to the accident. The talents and assistance of bioenvironmental engineers and aerospace physiologists may be invaluable in evaluating these factors. Further, he must correlate injury patterns with sequential crash events so that system failures, design deficiencies, or the lack of protective equipment can be determined and corrected. Many of the signs and symptoms on which the Flight Surgeon must base his diagnosis, are very transitory. For example, the key to the cause of a fatality can be destroyed by the simple act of moving a body during the crash control phase. For this reason, the Flight Surgeon must have his approach to accident investigation firmly in mind before an accident occurs. Triage and treatment of casualties are of utmost concern, but the Crash Ambulance Team must be prepared to preserve vital and fragile clues.

Phases of Medical Investigation

The medical investigation of an aircraft accident has three main phases: (1) Determination of the cause of death or injury; (2) human factors involved; and (3) evaluation of egress systems, personal and survival equipment, and rescue procedures and equipment.

Cause of Injury. The Flight Surgeon's approach to the analysis of injuries sustained in an aircraft accident should be *not* to accept the obvious as the whole truth. It is essential to identify the sequential injury patterns formed in the accident, egress, or survival phases of a mishap. The Flight Surgeon must evaluate the following factors in determining the cause of injury and correlate this evaluation with the entire accident picture in order to recommend remedial action:

Nature of the Injury. Injuries range from abrasions and contusions to complete fragmentation of the body. Even in badly fragmented bodies, a critical analysis of the injury pattern is necessary. The following examples illustrate the fact that critical analysis of wound patterns is vital in diagnosing the cause of accidents and detecting deficiencies in egress and survival equipment and safety design deficiencies of the aircraft:

a. A pilot and his seat were found at the site of wreckage of one of our fighter aircraft. At first glance, it appeared that ejection was initiated too late. An alert Flight Surgeon noted laceration-type wounds of the head, and upon examination of the aircraft control surfaces, found microscopically identifiable brain tissue. This indicated an ejection seat failure and led to design correction.

b. Analysis of the pattern of injuries sustained by victims of a commercial airliner that disappeared at sea, revealed the classic picture of free fall from great heights. Bodies were nude (wind blast will strip a normally clothed, free-falling body) and had little external injury; there was massive laceration of the great vessels and viscera, and little or no evidence of burns or explosive forces. This picture pinpointed the tragic design deficiency which caused the fuselage to split open at altitude, spilling the occupants out to free fall to the ocean.

c. A severe laceration of the groin in a person obviously dead from impact with the ground after his chute burned, revealed poor crew discipline, as the chute had been incorrectly donned in haste after the onset of the emergency. Opening shock plus a loose leg strap produced the laceration.

Escape and Survival. After determining the nature of injuries, the next question is, "Were the injuries caused or compounded by inadequate provisions for escape and survival?" *For example,* seat-man-chute interference has occurred in 10% of Air Force ejections, resulting in serious major injuries; burn injuries almost invariably have been associated with inadequate escape hatches and devices.

Decelerative Forces. Decelerative forces in accidents range from very mild to explosive impacts in which total disintegration occurs. Ironically, many fatalities occur in the very mild decelerative force range. The Flight Surgeon must correlate the injury pattern with analysis of the direction, magnitude, and the rate of onset of G forces to which an individual is exposed during the accident egress sequence. (A soft seat cushion, for example, negated body position restraints and also allowed the seat pan to accelerate while the cushion compressed. As a result, a number of vertebral fractures occurred in crash landings and ejections. A firmer cushion was the definitive fix.)

Personal Restraint Equipment. To analyze correctly the role of restraint equipment in the production of injuries, the following questions should be asked: "Was the injury due to failure of restraints, allowing the person to become a "far flung" object?" "Did the restraints themselves cause the injury, either by improper alignment with the G force (submarining effect of loose lap belt during ejection) or lacerations produced by high deceleration against loose restraints?" "Did the restraints prevent flailing injuries of the extremities?"

Shrapnel. Even a grossly disintegrated body should be closely examined for shrapnel wounds. X-ray of the remains is the best way to detect this. Two distinct classes of shrapnel should be considered:

a. Loose or poorly secured objects in the cabin which become missiles on deceleration. Even in an unsurvivable wreck, evidence of this type of shrapnel might prevent injuries in a subsequent survivable accident.

b. The explosive nature of a wound plus the presence of rigid and nonrigid shrapnel particles might be the first clue to an act of sabotage or combat injury.

Injury by Fixed Objects. Not only are anterior-posterior G forces experienced in the accident phase, but any and all axes may be involved. Thus, it happens that injury may result from a mild accident force when a properly restrained navigator strikes his head on a piece of navigational equipment. The Flight Surgeon should identify fixed objects that are hazards and recommend appropriate remedial action. If a person becomes a missile-like object, the chance of injury is greatly increased. However, design of the fixed interiors of aircraft can minimize injury. Such wounds and their mechanism of infliction should be identified so that remedial action can be effected.

Miscellaneous Causes of Injury. No cause of injury is too trivial to be thoroughly investigated and reported. A high index of suspicion is characteristic of a diagnostic mind, and it is this approach that detects previously unrecognized hazards.

Human Factors:

Accidents rarely happen because of a single act or omission on the part of the crew or because of a single mechanical failure. In reviewing Air Force accidents, it becomes clear that accidents occur as a mosaic of factors that blend together to form the tragic picture. In the performance of any complicated task, omissions, hesitations, or mistakes are to be expected. If you add to these bad weather, a fuel low level light, a background of worry over a sick child, and a body fatigued by a sleepless night, what is the result? Luckily, in the vast majority of cases, a safe penetration and landing result. However, when the end result is smoldering destruction, the Flight Surgeon must correctly evaluate the role and interplay of these factors in producing the complete crash "mosaic."

Before attempting to determine the human factors in aircraft accidents, the Flight Surgeon should have the accident picture clearly in mind. Human factors often can be correlated with a particular type of accident. For example, a power dive from FL 390, without radio transmission or attempted recovery, would certainly raise the question of pilot incapacitation. Therefore, an understanding of the types of accidents will aid in the human factor diagnosis.

Vertical Accidents. These accidents occur with an acute angle of impact. There is usually little or no wreckage, either human or mechanical, to provide clues to the cause. The accident investigator must rely on indirect evidence to make the proper decision. The presumptive diagnosis is usually made by "exclusion" in these cases. Figure 15-2 correlates vertical type accidents with environmental and human factors.

Horizontal Accidents. A thorough study of figure 15-3 makes it clear that pilot incapacitation is very unlikely in horizontal accidents. The more likely cause would be a deficiency in flight planning or discipline; also, distraction, inexperience, or preoccupation could be factors. (A commercial airliner was nearing minimums on an ILS approach when the copilot noted a minor deviation from course. He pointed this out to the pilot over the intercom and a correction back to course ensued. However, this correction continued past centerline and the jet transport was in a steep bank when the copilot took the controls and made an emergency go-around. The 48-year-old pilot was pronounced dead when the aircraft landed.) The above incident emphasizes the importance of keeping an open mind and investigating all possibilities in an accident. The odds against pilot incapacitation causing a horizontal type accident are great, but this one almost happened.

Psychophysiologic Factors. "Pilot error" is listed as a factor in the majority of aircraft accidents. This does not usually imply neglect or lack of skill on the pilot's part; rather, that the stresses to which he was subjected exceeded his psychophysiologic capability. In determining human factors or pilot error, three parameters of human performance must be evaluated: physiologic tolerances, behavioral responses, and physical condition.

Physiologic Tolerances. With the advent of high altitude flying, our aircrewmembers are exposed to the hazardous environment of reduced barometric pressure and reduced partial pressure of oxygen. *Hypoxia* and *decompression sickness,* insidious in their onsets, may incapacitate a flier before he is aware of his predicament. When he is engrossed in the complicated tasks of flying, he may be most susceptible to these conditions. In unexplained, high altitude vertical accidents, these factors should be thoroughly investigated. AFP 161-16 is recommended reading for the Flight Surgeon, especially if he is faced with this type of accident.

Vertigo or *spatial disorientation* is another condition which strikes with little or no warning. Vertical accidents from low altitude are typical of those caused by spatial disorientation. Intermittent weather/visual flight, transition from visual to instrument flying, bright, hazy days, and very black nights where ground lights are indistinguish-

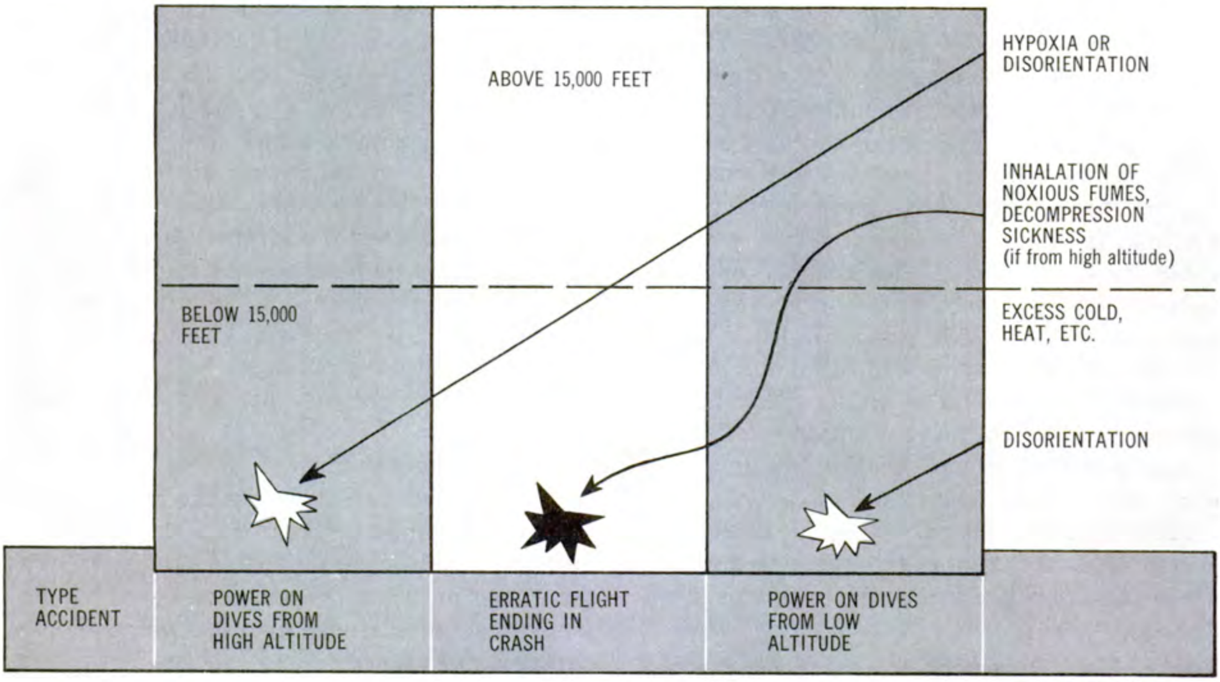


Figure 15–2. Vertical Type Accidents.

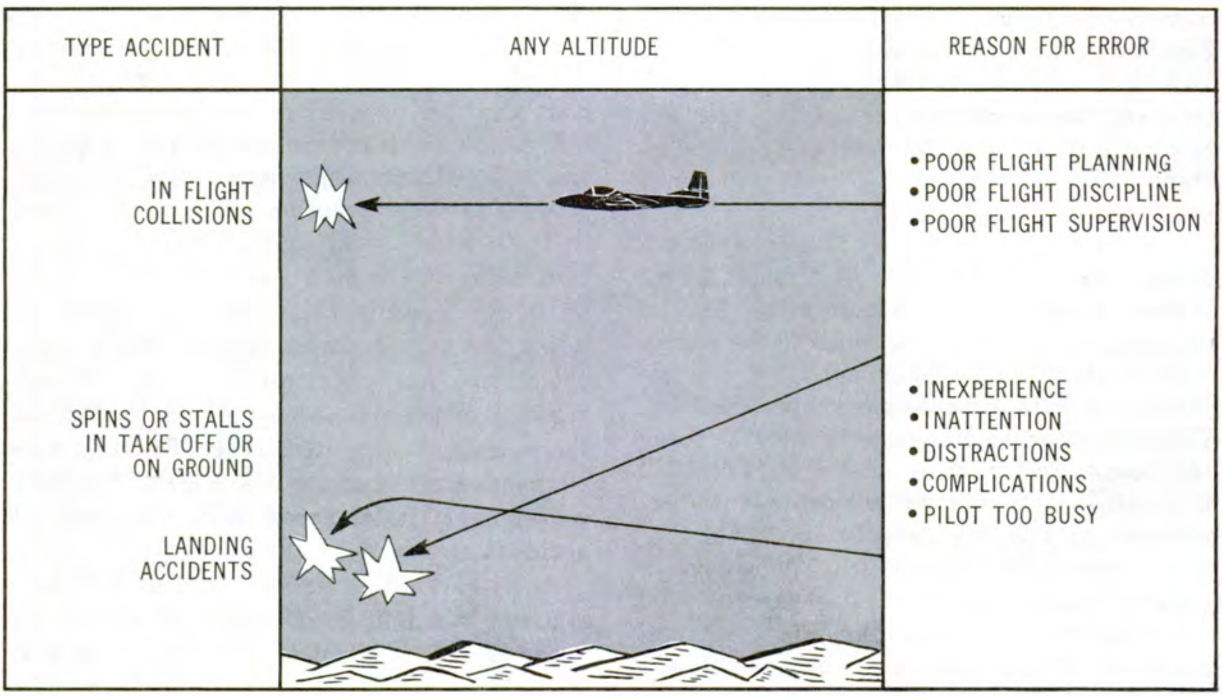


Figure 15–3. Horizontal Type Accidents.

able from stars, are conditions especially prone to cause spatial disorientation.

Behavioral Responses. The investigation of an aircraft accident should always include a detailed search for psychophysiologic and environmental factors. The investigating Flight Surgeon should evaluate all factors which could affect a pilot's ability to cope with the accident phase of a mishap. The behavioral responses of humans are unlimited and vary from person to person and from situation to situation. These variations in human behavior often provide the missing pieces in the aircraft accident mosaic.

The Flight Surgeon must not restrict himself to the accident phase, but must actively follow this line of investigation through the escape, survival and rescue phases also. This is the best guideline we have for developing our egress, survival, and rescue training.

The following factors must be considered:

Supervisory. An inadequate briefing or poor crew coordination, etc.

Preflight. A faulty flight plan or careless preflight of the aircraft might indicate an overconfident or unprofessional pilot.

Experience and Training. A pilot's total flying experience and training, and current experience with the type of aircraft are primary factors affecting his ability to cope with in-flight emergencies.

Design. Design—*i.e.,* location, lighting of controls and instruments, runway lighting, etc., should be carefully evaluated.

Communication. Problems of communication are definite factors causing accidents. Noise interference, misinterpreted or disrupted transmission, etc., must be determined.

Psychophysiological. Some of the most important are fatigue, self-medication, alcohol, hypoxia, distraction, overconfidence or lack of confidence, boredom, worry, and panic. Other factors, such as habit interference and task oversaturation are also important. The Medical Officer's Report form lists other possible psychophysiologic factors not mentioned here.

Environmental. These should be considered as they affect human behavior and performance. For instance, glare decreases visual capability, and excessive heat or cold is associated with performance decrement.

Source of Psychophysiological Data. The source of most of this data is obvious. Much of it can be obtained from the other Accident Investigating Board members. A careful analysis of medical records, unit duty rosters, and individual flight records will reveal possible medical or fatigue factors. The Flight Surgeon should attempt to get a picture of the pilot's personality if he doesn't know him. Interviews with fellow fliers, friends, and associates are useful. Finally, the Flight Surgeon must interview the family of a deceased crew member to determine specifically his activities immediately prior to the accident, and any possible emotional or family trouble. This is an extremely sensitive endeavor and must be left to the Flight Surgeon's judgment and experience as to how it should be handled. Excessive delay is to be avoided where possible.

Physical Condition. Physical incapacitation as the cause of an aircraft accident is uncommon. The physical condition of the aircrewmembers and the medical care and supervision which they receive contribute to this healthy state. The possibility of sudden incapacitation, such as an acute myocardial infarction, an acute loss of consciousness, or an epileptic seizure, should be suspected in any accident of unexplained cause. Further, self-medication with drugs which have undesirable effects may occur in spite of the efforts of the Flight Surgeon to educate his fliers. Review of medical records, questioning of associates and family members, complete post mortem examination with biochemical tests, and personal knowledge of the accident victim are all valuable means of establishing or disproving physical incapacitation as an accident cause.

Life Sciences Analyses of the Escape, Survival, and Rescue Phases:

Egress Systems. Ejections may be successes or failures. It is very important to investigate a successful ejection as it provides a base line against which ejection failures may be evaluated.

Successful Ejection. In order to completely investigate the circumstances surrounding an ejection, it is necessary to start with the emergency that prompted the ejection and investigate all the facets of escape to the point where the crewmember was recovered. The following checklist will serve as a guide for the investigation of a successful ejection:

Decision to Eject. The medical member of an Accident Investigating Board should determine why the ejectee decided that it was necessary to eject. Such a determination should be the result of objective consideration of all the factors, real or imagined, that caused this decision. If inability to cope with a malfunction caused an inexperienced pilot to eject from an aircraft that might have been saved, or if overconfidence caused a pilot to delay the ejection too long, this should be noted. It should be determined whether the pilot delayed ejection because he tried to avoid populated areas or unfavorable terrain, or tried to zoom to higher altitude.

Difficulties in Initiating Ejection. Ejection may have been delayed or made more difficult due to failure to remove safety pins, difficulty in locating actuating devices, excessive G forces, difficulty in removing canopies or hatches, inability to assume an optimal body position, or other problems. It is important that the investigator document these problems, even though the particular pilot survived. (The next man might not have as much time to overcome these difficulties.)

Aircraft Altitude, Attitude, and Airspeed. These factors should be determined as accurately as possible. Aircraft altitude should be determined for mean sea level and for terrain clearance.

Body Position. The position of the body at the time ejection was begun should be determined as accurately as possible and a description given of any tumbling, flailing, or other movements that occurred later.

Methods of Initiating Escape. The great variety of actuating mechanisms makes it necessary to determine which methods have been used most frequently and with the greatest success. It is important to note not only which actuating controls have been used, but also which hand has been involved in initiating the action.

Difficulties During Ejection. Once ejection is initiated, a multitude of hazards are encountered. Careful inquiry into the force and effect of ballistic and rocket catapults, wind blast, seat separators, and opening shock is in order. The failure or success of automatic devices for lap belts, seat separators, and parachute deployment should be determined. Collision of the seat with the parachute or the ejectee is common, and trace evidence of this should be diligently sought. Losses of equipment, flailing, tumbling, panic, disorientation, failure to release seat handles, and numerous other problems can occur.

Methods of Parachute Deployment. A number of devices, designed to provide quicker parachute deployment, are in use. The zero lanyard, the ballistically deployed chute, and a number of devices unique to a particular system may be used. A report should be made on the devices actually used and whether any attempt was made to beat the system with the D-ring.

Problems During Descent and Parachute Landing. The altitude above terrain at parachute opening should be determined as accurately as possible. The degree and persistence of oscillations should be noted, as well as any actions taken to stop oscillations. Technical Order 14D1-2-1, Mid-Air Modification for Steerability, deals with the "four line cut." Positive mention of the use or nonuse of this procedure should be made. Any other maneuvers or alterations used to control descent should be described. Deployment of survival kits or life rafts and inflation of underarm life preservers during descent should be reported. The direction the parachutist is facing in relation to his direction of travel along the ground is important. His travel may be due to wind, oscillation, or both. His body position at ground contact and any maneuvers performed to lessen impact should be noted. Any problems, such as dragging over the ground or in the water, or difficulty in releasing risers, should be investigated carefully.

Parachute Landing Conditions. The terrain and surface winds should be described accurately. The total weight suspended under the parachute should be given, noting how much represents equipment, seat, and man, respectively. Often, the seat will pass through or hang up in the parachute, and this should always be reported.

Unsuccessful Ejection. An unsuccessful ejection may occur at any point from the initiation of the ejection sequence to the safe rescue of the ejectee. In the investigation of an unsuccessful ejection, the relative positions of the aircraft canopy, the seat/man mass, and the crash are extremely important.

If body/seat and wreckage are found together, but canopy has been jettisoned:

Estimate time between jettisoning of canopy and crash. A long time could indicate system failure, or inability to initiate ejection due to incapacitation or high G forces.

Note method of canopy removal —*i.e.*, leg brace, T-handle, etc.

Check position of seat triggers to determine whether they have been activated.

Check seat pins in leg brace initiator. Seat pins left in can delay or negate an ejection.

Check pilot helmet for evidence of possible damage by contact with canopy.

Check chute straps, lap belt, zero lanyard, and chute arming lanyard (Gold Key) for proper attachment. The pilot might delay ejection too long, attempting to fasten or attach one of these items.

If canopy has not been jettisoned, check position of leg brace or other canopy jettisoning system—*i.e.*, "T-handle." Even with canopy jettison failure, through-the-canopy ejection is possible. The delay might be fatal, however.

If both canopy and seat have exited the aircraft:

Estimate altitude, indicated air speed (IAS), and attitude of escape by plotting wreckage fallout. Overconfidence in an egress system may cause delayed ejection.

Determine whether man-seat separation occurred before or after impact.

Determine whether seat separator functioned. Check tautness of straps.

Check degree of chute deployment.

Check method of deployment—*i.e.*, zero delay lanyard, F–1B automatic timer, or D-ring.

Check the seat and the chute for location of "Gold Key." This could indicate the nonuse, misuse, or "inadvertent" opening of the lap belt.

Check to see if the manual lap belt latch is open, and if so, why.

Look for evidence of seat/chute involvement. If chute is damaged, check carefully for paint from seat. Severed suspension lines usually indicate damage by seat.

Look for evidence of seat/man involvement. Here, the type of injury can point to seat/man involvement. (One Investigating Board had concluded that ejection had been initiated too low. However, the Flight Surgeon matched a linear crushing chest wound with the top edge of the seat and proved seat/man involvement.)

Personal and Survival Equipment. Personal and survival equipment of accident victims often contains many important clues to accident mishaps. The personnel who arrive first on the scene often destroy these clues in their eagerness to help a casualty. The following approach will minimize this loss: *First,* photograph the equipment before moving the casualty/remains, if possible; *second,* preserve all items of equipment/clothing for subsequent analysis; and *third,* if treatment dictates removal of clothing, preserve the ventral surface. The front of a flying suit, etc., will usually have more clues. Powder burns on the lap area, *for example,* can prove that the lap belt separator fired.

A complete listing of all equipment used by persons involved in an accident must be made. Personal equipment specialists can provide assistance in obtaining correct model designation and nomenclature. (*For example:* "Helmet, HGU-2/P.") The following categories of equipment will be involved in most accidents:

Clothing. Helmets, gloves, boots, and thermal or fire-retardant clothes.

Oxygen. Masks and regulators used by crews. Special attention should be given to emergency oxygen equipment for passengers subjected to rapid or explosive decompression. Decompression sickness is rarely encountered as a cause factor in aircraft accidents. However, careful analysis of each case is mandatory to establish the adequacy of present procedures, equipment, and operational restrictions where passengers are involved.

Flotation Devices. Their availability and number, and problems of launch are factors to be investigated.

Seats and Restraints. In addition to crew restraints, a careful analysis of passenger restraint systems must be made. Analyzing the restraint/seat failure pattern and the injury pattern resulting from failure will establish guidelines for future R&D.

Parachutes. The type of chute, opening/deployment devices, and canopy release should be recorded.

Survival Gear. Survival kits, radios, and other signaling devices.

Method of Life Sciences Analysis:

Determine whether the requirement for the item of equipment was established by Air Force directive or was a personal or base development.

Determine availability of the item of equipment in the aircraft at the time of the accident.

Determine phase of mishap in which the item of equipment was used, needed, discarded, lost, or failed. (Phases of mishap are (A) Accident, (E) Escape, (S) Survival, and (R) Rescue.)

Document any problems experienced that involved equipment, to include supply problems as well as malfunctions.

Survival and Rescue Experience:

The Korean and Vietnam conflicts dictated the need for an improved survival and rescue capability. The Air Force expended all its technologic resources in producing training facilities, equipment, and techniques currently used. They are the best the "state of the art" has produced. However, a look at the statistics reveals that a number of crew members survive the accident and escape phases, only to be lost during the rescue phase.

The avoidable loss of even one flier is a justification for systems improvement. Systems improvement must be based on a valid analysis of all survival/rescue parameters. AF Form 711gA, "Life Sciences Report of an Individual Involved in an AF Accident/Incident—Section A, Aircraft Accident/Incident" is devoted to a comprehensive analysis of this problem. The following are some of the parameters which may play a role in rescue:

Background training.

Environmental conditions.

Time sequence of rescue events.

Personnel/vehicles available and utilized in rescue.

Rescue equipment available and utilized.

Alert/communication methods and problem areas.

Search procedures.

The Flight Surgeon conducting the analysis should use AF Form 711gA to guide his investigation. It should not, however, be taken as a limit to his investigative efforts. Any new factor should be carefully evaluated and recorded.

Photography

Reference has been made repeatedly to the importance of photography in accident investigation. The following procedures are important in this phase of the investigation:

Photograph bodies to show relation to crash site, ejection seat, or any orientation point.

Take a closeup photograph to demonstrate equipment position or a possible mechanism of injury, before body is moved.

Photograph bodies, front and back, with

all equipment in place; also, front and back, nude. This combination of dressed and nude photographs will correlate injuries related to personal equipment. (This will also apply to casualties wherever possible.)

Take photographs in color and in black and white.

Equipment. Large hospitals with medical illustration departments are authorized the necessary camera equipment. These same facilities usually supply pathology support for aircraft accident investigation, and the medical photographer is part of the team. Smaller facilities must rely on the base photographic personnel. The Flight Surgeon should consult these individuals to work out procedures that will insure good photographic support for Life Sciences investigation prior to the occurrence of an accident.

Reports

AFR 127-4 establishes the requirement for formal reports of Air Force mishaps. The formal report of an Air Force aircraft accident is prepared on AF Forms 711 series. AFM 127-2 provides the format and guidance for proper completion of this report. The medical officer on the Investigating Board is responsible for the completion of AF Form 711gA.

The evaluation of Life Sciences factors in aircraft mishaps has been a laborious process involving much manual processing of accident reports. The conflict in Vietnam generated the requirement for faster detection and analysis of trends, especially in the areas of egress, escape, survival, and rescue. To meet this requirement, an automatic data processing capability is being established within the Office of the Deputy Inspector General for Inspection and Safety. Further, AF Form 711gA has been revised and expanded to make it adaptable to this automatic data processing system.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Aerospace Medicine*, Williams and Wilkins Co., Baltimore (1961).

Aerospace Safety (Periodical).

Aerospace Maintenance Safety (Periodical).

AFM 127-1, *Aircraft Accident Prevention and Investigation.*

AFM 127-2, *USAF Accident/Incident Reporting.*

AFM 143-1, *Mortuary Affairs.*

AFM 160-19, *Autopsy Manual.*

AFM 160-28, *Methods of Preparing Pathologic Specimens for Storage and Shipment.*

AFM 160-37, *Medical Planning for Disaster Casualty Control.*

AFM 161-2, *Conducting the Aerospace Medicine Program.*

AFM 168-4, *Administration of Medical Activities.*

AFM 355-1, *Disaster Preparedness—Planning and Operations.*

AFR 127-1, *Responsibilities for USAF Aerospace Accident Prevention Programs.*

AFR 127-4, *Investigating and Reporting USAF Accidents/Incidents.*

AFR 127-301, *Reporting Operational Hazards.*

AFR 143-3, *Care and Disposition of Remains When Multiple Deaths of Members of Two or More Services Occur as Result of Disaster or Major Accident.*

AFR 160-55, *The Armed Forces Institute of Pathology and Armed Forces Histopathology Centers.*

AFR 160-88, *Medical Responsibility in Disaster Control.*

AFR 160-109, *Medical Investigation of Aircraft Accident Fatalities.*

AFR 160-127, *Joint Committee on Aviation Pathology.*

Chapter 16

EMERGENCY EGRESS (AIRBORNE) FROM AIRCRAFT

As aviation has progressed, it has become apparent that greater effort must be expended in the development of safety devices used in escape from disabled aircraft. In 1920, a rule was established that required fliers to carry and use parachutes. This was the beginning of positive measures undertaken to increase the aircrew's chance of survival.

Now, supersonic speed, coupled with very high altitudes, has greatly multiplied the problems of escape. The epochal jump from 40,200 feet made by Colonel Randolph Lovelace, MC, 24 June 1943, served to reveal many of the dangers associated with bailout from extreme altitudes. Coincident with the opening of his parachute at high altitude, he became unconscious and lost the glove from his left hand. When he regained consciousness, he was suffering from shock, a sprained back, and frostbite injury to his left hand. The thin nylon glove remaining on his right hand was sufficient to protect it from frostbite. Oxygen was supplied by several H-2 bailout bottles during his descent.

In July of the same year, Major P. J. Ritchie made a successful 32,000-foot emergency jump without oxygen, holding his breath during the long free fall. He did not pull his ripcord until he felt himself on the threshold of unconsciousness. Nevertheless, he suffered injuries from the severe opening shock at 27,000 feet.

In 1944, a series of high-altitude dummy drops provided information which showed that opening shock was greater at high altitude than at lower levels. However, it was not until the summer of 1950, when a series of jumps demonstrated the feasibility of high-altitude bailout, that reliable information was obtained at and below the level of 42,000 feet, with recordings of pulse rate (ECG), respiration, skin temperature (nape of neck and dorsum of hands and feet), time, and altitude.

On the other hand, bailout at very low altitude has been the greatest cause of loss of life. The problem here has always been one of getting the flight crew out of the airplane in sufficient time to get their chutes open before they hit the ground.

PARACHUTE EQUIPMENT

There are three main parts to any parachute assembly: the pack, the harness, and the canopy. The Air Force uses three basic parachute packs (back, seat, and attachable chest), and there is no difference in their operating reliability.

One type of personnel parachute canopy is used throughout the Air Force for both emergency bailouts and ejections, that is, the C-9. The canopy is fabricated from mildew-proof nylon and is 28 feet in diameter. (*Exception:* F-4 aircraft employs 24-foot canopy.) It has a high coefficient of drag and is sufficiently stable for most applications.

The requirement for a seat or chest style parachute is dictated by the emergency escape exit, seat configuration, and the operational requirement. TO 14D1-1-1 directs the style of parachute to be worn on a given aircraft by a crewmember or passenger. Some generalizations are furnished in the interpretation of TO 14D1-1-1.

Back Parachute

The back parachute is preferable for general use. The harness is readily adjustable and allows slack for comfort during flight, yet can be quickly tightened prior to bailout.

Crewmembers of all Air Force fighter aircraft except the F-111 use an automatic back parachute. The F-111 has a separable crew escape compartment which is lowered to the surface by its own 70-foot diameter chute. The F-4C aircrewman uses a back parachute which is an integral part of the seat. The crewmember is required to wear a special harness which he attaches to the stowed parachute.

Crewmembers of Air Force helicopters are required to use nonautomatic, back-style parachutes.

Seat Parachute

The seat-style parachute is in limited use, being used chiefly in training aircraft. When worn with a survival kit or life raft, the seat parachute assembly is quite bulky and heavy, making movement to and through emergency exits difficult. Due to its location on the body, this assembly does not adapt well with other accessories and thus, has limited usefulness. Usually, it hinders escape more than does either the chest or back-style parachute. Because of these limitations, the seat parachute is used only on the A-1E, B-57, T-28, and T-33 aircraft.

Attachable Chest Parachute

The attachable chest parachute is used only when there is no provision for either a back or seat parachute. The harness can be worn separately from the parachute pack for comfort. The faults of this chute, however, outweigh the advantages. Crewmen have been unable to reach stowed parachutes in time for bailout because of high G forces, fires, explosions, and their movement to distant locations within the aircraft during the emergency. During the high emotional tension of an emergency, men have forgotten to fasten the pack to the harness prior to bailout.

This type of chute is worn by passengers on the following aircraft: WB-50F, HC-47D, KC-97G, C-118, C-121G, C-131A, C-135F, VC-118, VC-137B, VC-137C, T-29A, CT-29A, VT-29C, U-3A, U-3B, HU-16A, and HU-16B.

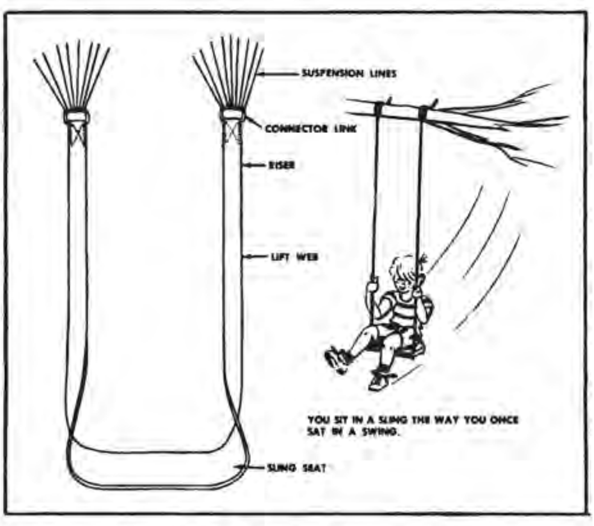


Figure 16-1. Basic Harness Sling.

Harness

There are two general harness configurations used throughout the Air Force for emergency bailouts: Class III and Class IV. Though construction details differ, either class can be adjusted if one understands the basic system of harness construction.

Every harness starts as a loop of webbing called the "sling." (See figure 16-1.) This loop is just like a child's swing and works in the same way. Both ends of the swing are attached to the parachute suspension lines, much the same as a swing is attached to a tree.

The sling is designed to take the largest part of the parachute-opening force. If the body position during bailout could always be controlled, only the sling portion of the harness would be needed for a safe jump. Since the sling will not stay in a fixed position by itself, leg, back, and chest straps are added to the harness to keep the parachutist from falling out of the sling.

Figure 16-2, *View A*, shows a harness sling and the added straps. For clarity, no hardware is shown. *View B* illustrates the same harness assembled with hardware. On Class III harnesses, the length of the main sling may be changed by moving the sling webbings through the mainsling adjuster. On Class IV harnesses, taking up the adjustable leg strap results in tightening of the sectional main sling and integrated back straps. (See TO 14D1-2-1 for sizing and adjustment procedures.)

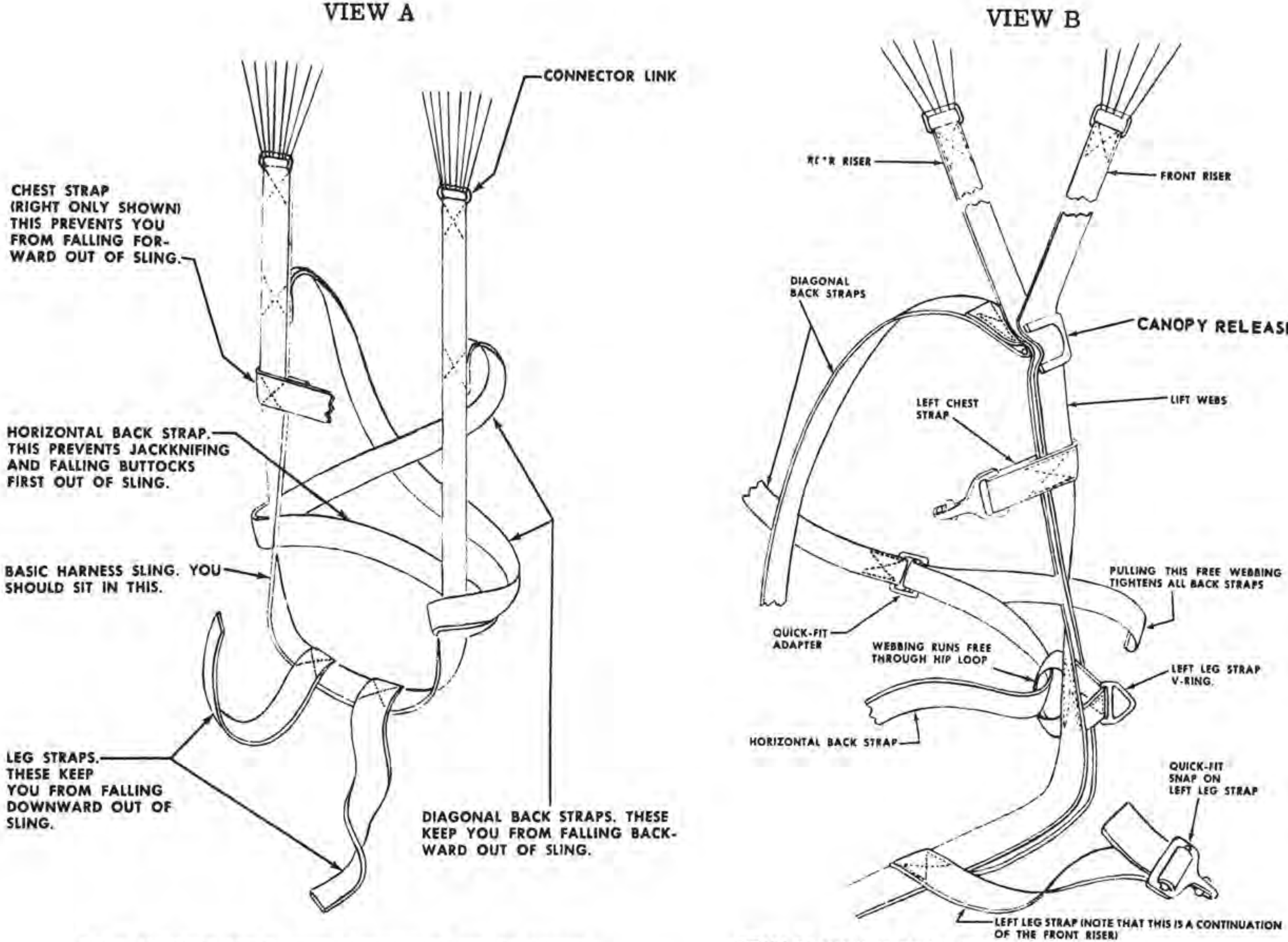
Automatic Safety Belt

The ejection seat is equipped with a Type MA-6 automatic opening safety belt (figure 16-3) which, in conjunction with the ejection seat and automatic parachute, comprises an automatic escape system, extending the maximum and minimum altitudes at which escape may be successfully accomplished. In a low-altitude ejection, use of the automatic system greatly reduces the time required for separation from the seat and deployment of the parachute, and consequently, reduces the altitude required for safe ejection. The automatic safety belt has been thoroughly tested and is completely reliable. No matter how fast a pilot's reactions, he cannot beat the automatic operation. The belt is cartridge-operated for automatic opening during seat ejection. Automatic operation is accomplished during seat ejection by gas pressure from a separate, automatically controlled initiator which supplies pressure through a length of high-pressure hose that actuates a piston inside the belt, retracting the latch tongue, and releasing the belt swivel link. The link accommodates an anchor on a lanyard leading to the parachute automatic timer. When the belt is manually opened, the anchor is released automatically so that the inadvertent actuation of the automatic parachute will not occur.

In some aircraft, the ejection seat is equipped with a seat-man separator that operates automatically as part of the seat ejection sequence and requires no additional effort on the part of the pilot. The system consists of a web strap assembly shaped like an inverted "Y," and a cartridge-operated actuator. Two straps attached to the forward edge of the bucket seat are routed under the survival kit to the yoke from which a single strap is routed up the face of the seat, back to the actuator behind the headrest. When the seat is ejected, a trigger on the seat is tripped, causing an actuator to fire. This action causes the web strap assembly to be drawn taut, effectively displacing the survival kit and separating the pilot from the seat. Upon separation from the seat, the parachute lanyard, still attached to the open safety belt, actuates the parachute timer, or pulls the ripcord grip directly if the zero-delay lanyard is connected. The zero-delay lanyard is discussed in more detail later on in this chapter.

METHODS OF EGRESS AND EGRESS SYSTEMS

For the pilot flying at subsonic speeds, the problem of escape has been satisfactorily answered by open-seat ejection. The seat is ejected from the aircraft in an upward or downward direction by a catapult of appropriate design. The rocket-type catapult per-



BASIC HARNESS SLING WITH SUPPORTING STRAPS ADDED

DETAILS OF ASSEMBLED TYPICAL HARNESS (COMBINATION OF SEVERAL ACTUAL TYPES)

Figure 16–2. Harness Construction.

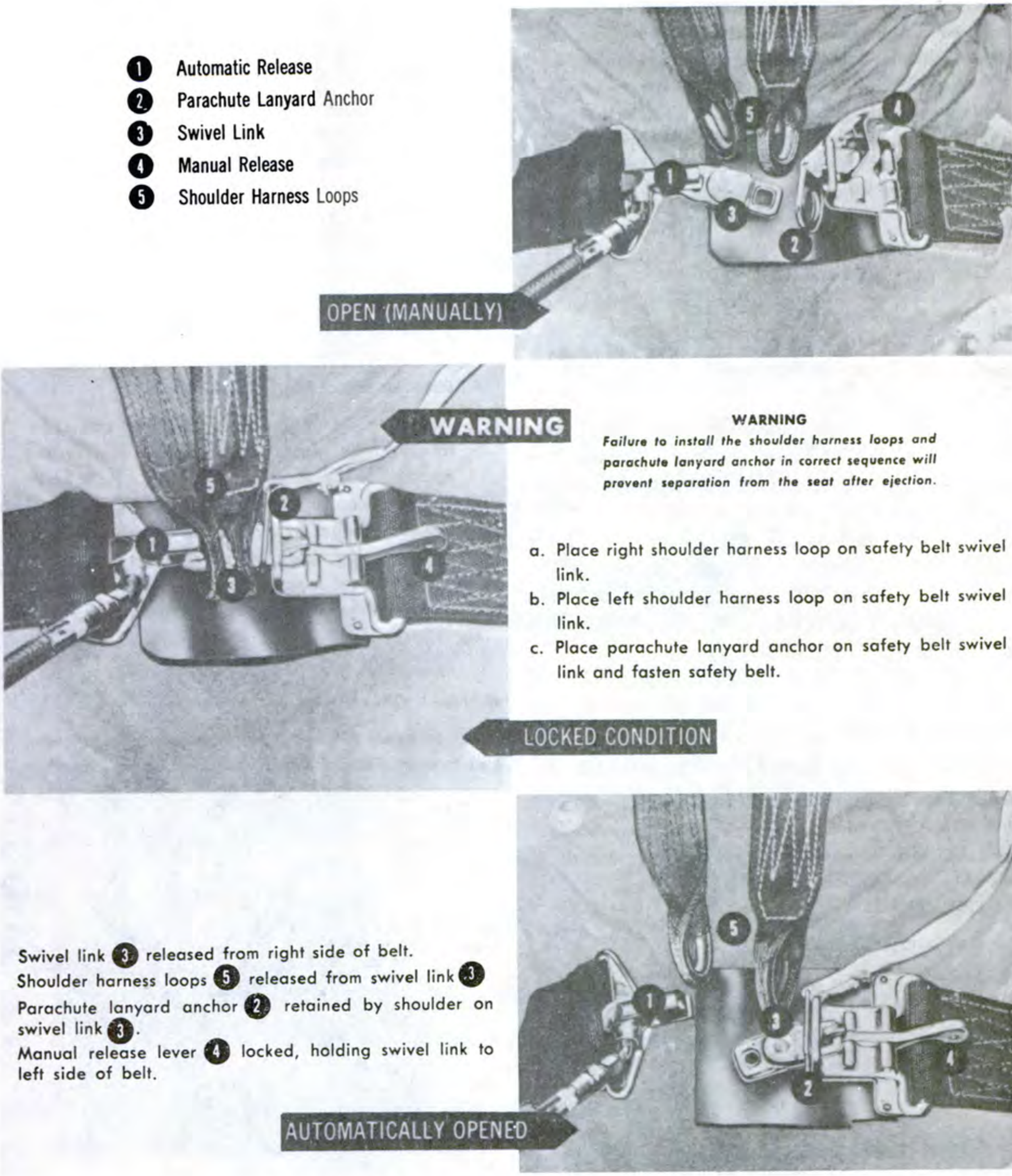


Figure 16–3. Automatic Safety Belt, Type MA–6.

mits higher ejection velocity without exceeding the maximum permissible acceleration and "jolt," because such catapults have no inherently limited "stroke length."

At a given altitude, the force exerted by windblast on a given area increases as the square of the true airspeed. Windblast problems become acute beyond 500 knots indicated air speed (IAS), and at 660 knots (Mach 1 at sea level) become quite critical.

At this speed, windblast exerts over 9 psi, or a total of 3½ tons over the surface of the body. This pressure is not, *per se*, injurious to tissue, but makes retention of personal equipment exceedingly difficult. It can cause extreme flailing of limbs and head, and hence, secondary injury.

However, ejections at indicated airspeeds above 500 knots are quite rare. In general, pilots using currently standard Air Force equipment, and using it in the proper manner, can expect to bail out uninjured.

Separation From the Seat and Parachute Opening

One of the first considerations after ejection is separation from the seat. It is advisable for the subject to release his safety belt and shoulder harness and kick clear from the seat as soon as possible after ejection. There are reports on record of cases in which the pilot ejected himself from the plane, but was still fastened in the seat by the safety belt at the time it crashed into the ground. In these cases, the seat chute failed to deploy when the ripcord was pulled because of the restriction imposed by the seat.

When the seat leaves the aircraft, the lap belt initiator is armed, and, following a one-second delay, the lap belt is blown apart. In the event of a malfunction, the belt may be manually opened. However, if this occurs, the automatic parachute release is bypassed and the ripcord will have to be operated manually.

When the F–1B automatic parachute release (figure 16–4) is installed in the parachute pack, one need have no fear of delayed opening or entanglement of the chute on the aircraft structure. The automatic parachute release aneroid is set at 14,000 feet, and the time setting is 1 second when used with an automatic lap belt. When used in a nonejection-seat aircraft, the timer is set at 5 seconds. This provides a sufficient time interval to avoid the aircraft and to approach terminal velocity. The automatic release can be overridden in an emergency, but under no circumstances should the chute be operated before a one-second delay.

It should be pointed out that altitude may be difficult to judge when one is over water or desert terrain. Having the aid of the F–1B, there is no reason for opening the chute at high altitude, and very little reason to use the manual release.

Manual Parachute Release. When it is necessary to pull the ripcord manually, the jumper should first look at the "D" ring. If a back or seat-style parachute is being used, the thumb of the left hand should be hooked into the ring and the assembly rotated outward from the body. The right hand then should grasp the "D" ring which is then pulled with both hands away from the body with a hard and fast motion. When a chest-

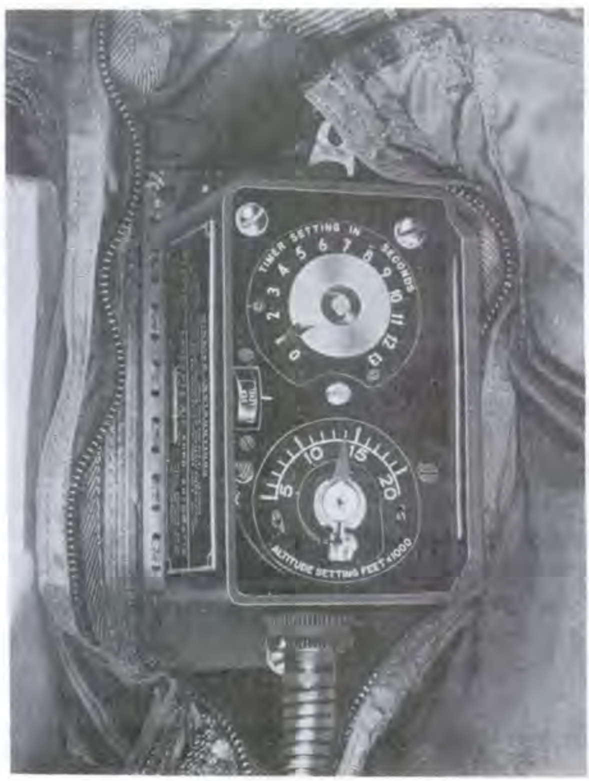


Figure 16–4. F–1B Automatic Parachute Ripcord Release, in the Latest Back Type Parachute.

The release consists of an anaeroid and time setting. An anaeroid setting of 14,000 feet will be maintained at all times. A one second time setting will be used when used in an ejection seat. For use in aircraft with conventional seats, a five second time setting will be used.

type parachute is used, the bottom of the pack is held with the left hand, and the right hand pulls the "D" ring with a hard, fast jerk.

Low Altitude Escape

Most fatal ejection attempts are from low rather than very high altitudes. In an attempt to lower the minimum safe ejection altitude, a timing system has been developed which causes immediate chute deployment when the pilot leaves the seat. This is called the "one and zero" system, meaning seat separation one second after ejection and chute deployment at that time. This system has been found to give ground level escape capability, using certain catapults and traveling above a certain airspeed.

This is accomplished by a very simple arrangement (figure 16–5). While flying at altitudes below 2,000 feet, the lanyard, which ordinarily arms the timer when the pilot leaves the seat, is snapped directly to the "D" ring.

Before the takeoff, the pilot inserts the automatic parachute lap belt key into the seat belt, in accordance with standard procedures. The snap ring is then attached to the parachute "D" ring. Upon reaching a reasonable flight altitude (2,000 feet), the snap ring is disengaged. No further action is necessary since the automatic parachute release arming knob is never disengaged from attachment to the seat belt. Prior to landing and during low altitude flights, the pilot again attaches the snap hook to the "D" ring. Zero-delay lanyard engagement requirements and method of attachment are shown in figures 16–6 and 16–7, respectively.

High Altitude Escape

As altitude increases, several problems of escape become more acute. These include (1) bailout oxygen supply, (2) cold exposure, (3) decompression, and (4) parachute opening shock.

The problems of escape at high altitude virtually dictate that the crewman free-fall to a pressure altitude of 15,000 feet before his parachute is deployed. Seat separation, free-fall, and chute deployment are accom-

Figure 16–5. Arrangement of Arming Accessories, Automatic Back Parachute.

plished by a group of automatic devices designed to provide a dependable means of getting the crewmember to a lower altitude safely. The free-fall technique of high-altitude ejection seat escape becomes less satisfactory at altitudes above 40,000 feet since dangerous rates of spin are encountered at these altitudes. Nevertheless, the use of this technique and reliance on the parachute timer offer the greatest measure of safety.

Bailout Oxygen Supply. To combat hypoxia, the standard bailout aid, usually used in the Air Force for oxygen masks, is a small, high-pressure (1,800 psi) oxygen bottle (H–2) (see figure 16–8). Pilots of fighter-type aircraft should carry the bailout bottle on flights above 25,000 feet to provide oxygen in cases of egress. This bottle is located on the parachute and is attached to the oxygen mask with a hose and bayonet fitting via a

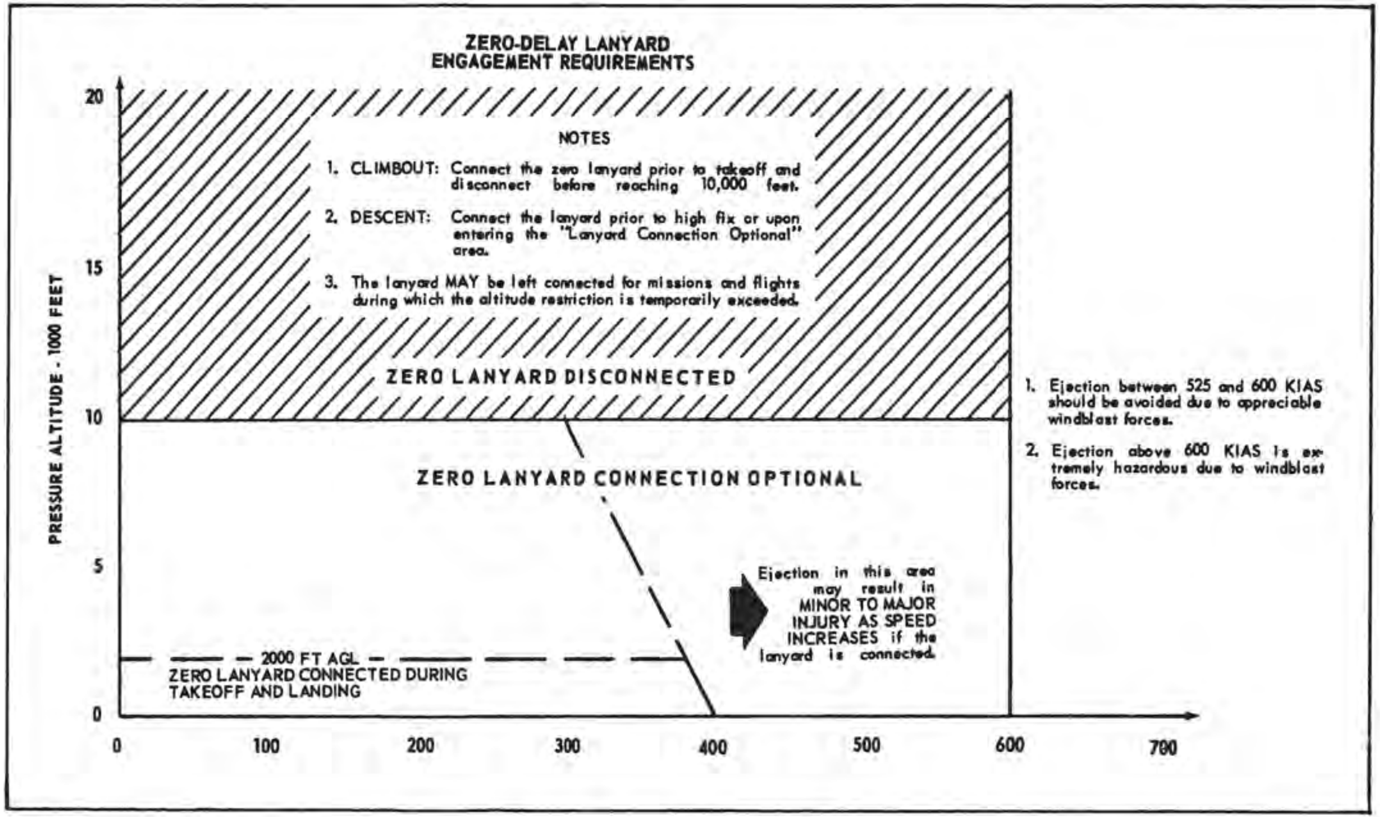


Figure 16–6. Velocity—KIAS.

Figure 16–7. Method of Attaching Lanyard Hook to Ripcord Grip.

connector (CRU–60). Certain aircraft (F–4, F–106) carry the emergency oxygen in the survival container. It will supply a continuous flow of oxygen for approximately ten minutes.

With the H–2 system, the flow rates (at 25° C, 760 mm Hg) will vary from ten liters per minute during the first minute to one liter per minute at the end of a 10-minute period. Free fall descents from a maximum altitude of 40,000 feet can be accomplished when using demand masks (MBU–4), and from 50,000 feet when using pressure breathing masks (MBU–5) in conjunction with the CRU–60 connector. Even from these altitudes, the bailout bottle is not expected to supply oxygen for a long open-parachute descent, but is intended to carry the free-falling parachutist to lower altitudes safely and without danger of unconsciousness from hypoxia. Altitudes above 50,000 feet require bottles of larger capacity to supply the oxygen under pressure to the high-altitude pressure suit and mask. Fighter pilots bailing out with the Type H–2 assembly must actuate the valve of the bailout bottle, disconnect the oxygen-mask hose, release the canopy, and fire the ejection seat. In certain aircraft (F–4, F–106), actuation of the bailout assembly is accomplished automatically by the motion of the ejection seat as it leaves the aircraft.

It has been proven that the H–2 bailout bottle provides a satisfactory supply of emergency oxygen. However, in escape above the 20,000-foot level, the oxygen contained in the bailout bottle would probably be insufficient for some bomber crewmen, considering the time required to reach and open escape hatches and still provide for the increased

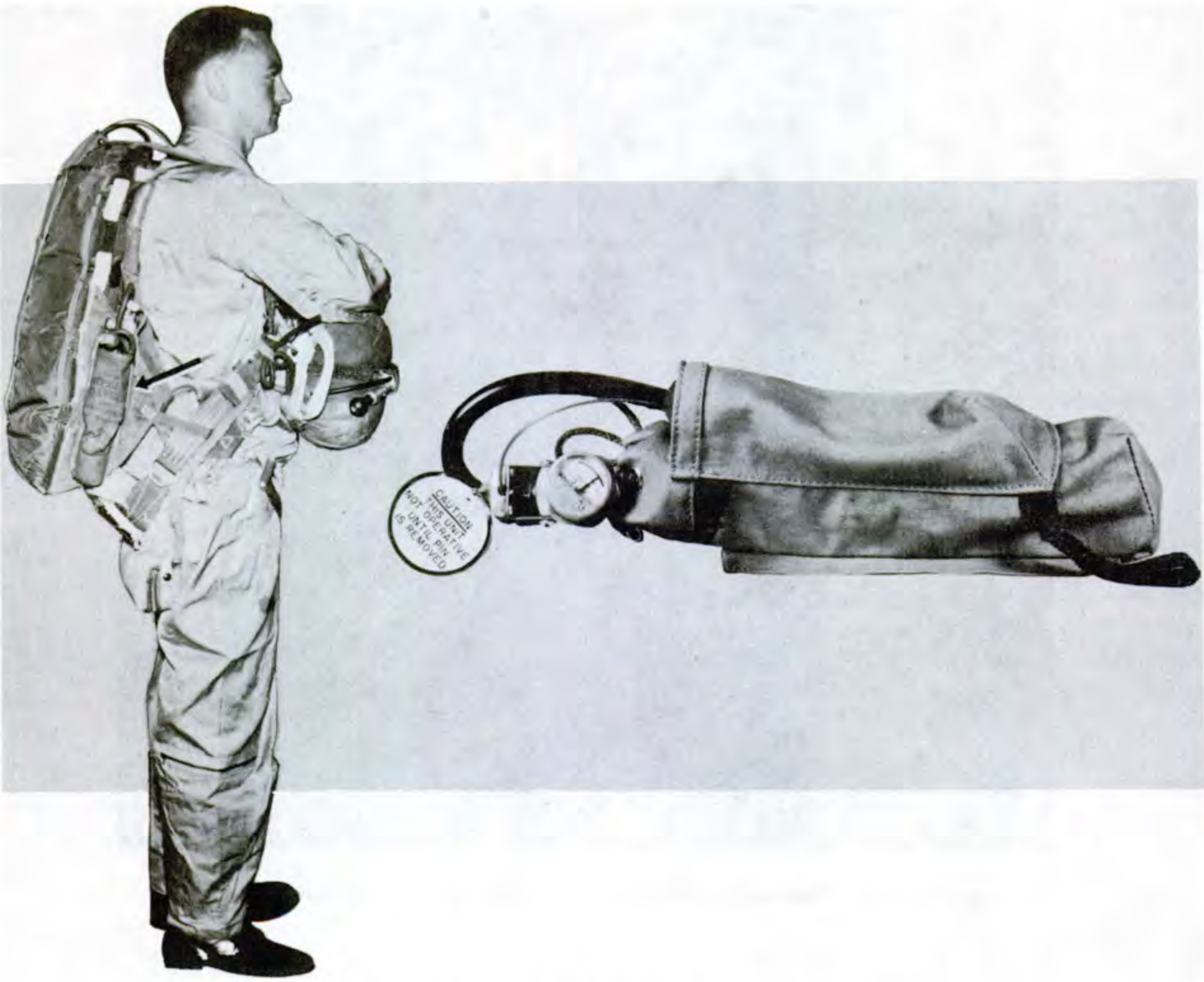


Figure 16–8. The H–2 Bailout Bottle and Canvas Container.

The figure at the left shows one method of attaching the bailout bottle (H–2) to the parachute pack (arrow).

metabolism from excitement and exercise. In such situations, crewmembers should use the walk-around bottle to reach the escape hatch and then transfer to the bailout bottle.

Cold Exposure. A body falling freely through space is not unduly influenced by the cold windblast. The extremely low temperatures at high altitudes affect the parachutist for such a short time that there is no reason to fear frostbite. During a free fall, the individual may experience some degree of frostbite unless all parts of the body are fully covered with clothing approximating 2 *clo* value. (The *clo* is defined as that amount of insulation which will maintain normal skin temperatures when heat production is 50 kilocalories per square meter of body surface per hour, air temperature is 70° F, and air movement is 20 ft per min.) (See chapter on "Effects of Temperature.")

Decompression. (The effects of decompression are discussed in the chapter entitled, "Effects of Decreased Barometric Pressure —Dysbarism.")

Parachute Opening Shock:

Opening shock in terminal free fall at 5,000 feet is 5 to 8 Gs peak acceleration. The opening shock at high altitudes is more severe; the rate of opening of the parachute canopy is much faster since the lighter air

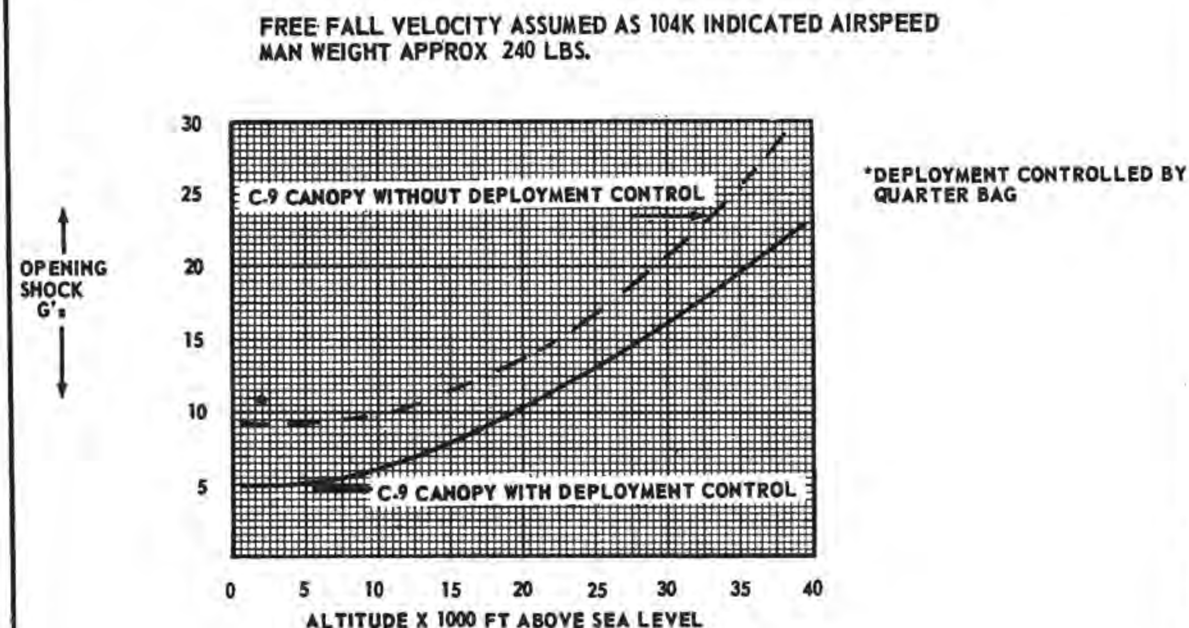


Figure 16–9. Average Opening Shock 28 Foot Parachutes at Various Altitudes at Terminal Velocity of Average Crewman.

at high altitudes offers less resistance to the expanding skirt of the canopy. This allows complete deployment and opening in a very short time. (See figure 16–9.)

The effects of increased terminal velocity are obvious since velocity actually doubles at an altitude of 40,000 feet when compared to that at sea level. As one ascends, the increase in terminal velocity is responsible for an increase in the magnitude of deceleration at higher altitude. Higher terminal velocity is attained as air density decreases. Approximate values are as follows:

40,000 feet terminal velocity—243 mph
30,000 feet terminal velocity—196 mph
10,000 feet terminal velocity—140 mph
SL feet terminal velocity—120 mph

Parachute packs used on aircraft having ejection seats have their canopy packed in a "quarter deployment bag" (figure 16–10). This bag encases approximately one-fourth of the folded canopy. Suspension lines are stowed in channels (flutes) on the outside of this bag. Parachutes packed in this manner are restricted from use in slower helicopters and liaison aircraft. The quarter deployment bag facilitates the orderly deployment of suspension lines and canopy, and decreases opening shock.

Capsule Ejection

The Handbook of Instructions for Aircraft Design (HIAD) specifies that any aircraft flying above 50,000 feet or above 600 knots IAS must provide an inclosed escape system, or capsule. Escape capsules reduce such problems as windblast, cold, and low pressure, and extend escape capabilities at high speeds and altitudes (see figure 16–11).

The F–111 aircraft is the first operational aircraft designed to provide a separable crew compartment (see figures 16–12 and 16–13).

A comparison of the characteristics of this type of escape system and the encapsulated seat (B-58) is shown in table 16-1 (see also figure 16-14).

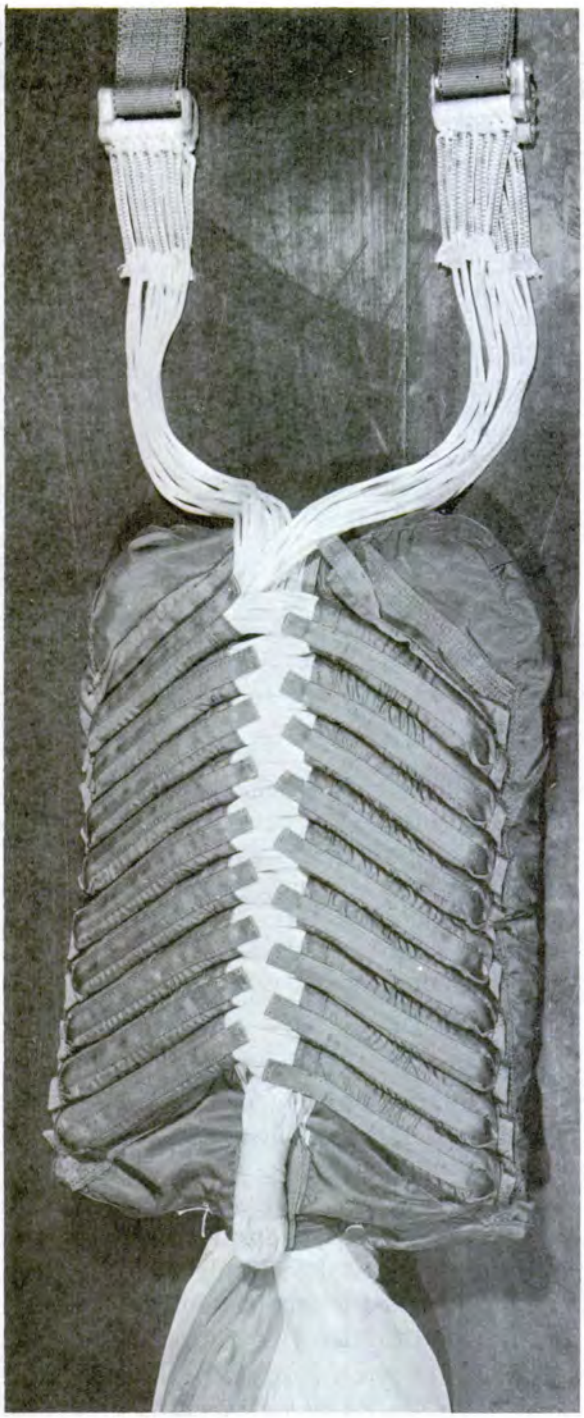


TABLE 16-1. COMPARISON OF ENCAPSULATED SEAT AND SEPARABLE CREW COMPARTMENT

Condition	*Encapsulated Seat*	*Separable Crew Compartment*
Human tolerance	Good to 700 KEAS	Goal of 900 KEAS
Aerodynamics and stability	Good	Good
Man/seat/chute collision	Not possible	Not possible
Collision between ejectees	Possible	Not possible
Minimum time — Low altitude ejection and recovery	7 to 10 seconds	8 to 12 seconds
After landing survival	Good	Excellent
Relaxation and comfort	Poor	Improved
Backup pressurization	Good	Poor
Bailout coordination	Necessary	Improved over ejection seats or single capsules

Figure 16-10. Quarter Deployment Bag.

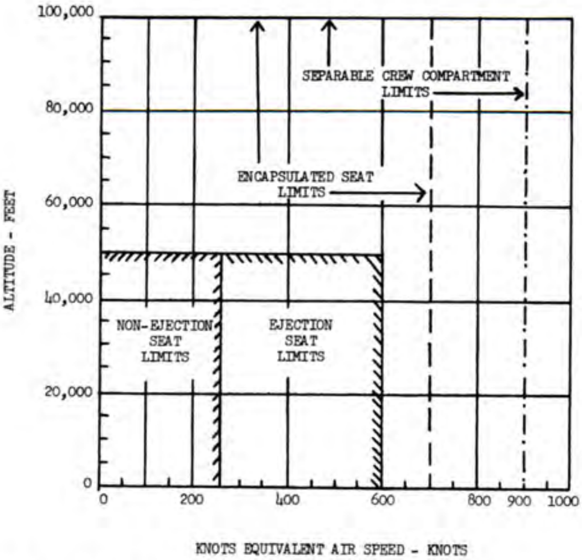


Figure 16–11. Escape Provision Requirements.

Manual Bailout

When aircraft are not equipped with ejection seats, situations may develop which will make escape difficult or impossible.

An adequate warning system is essential to alert all flight personnel so that each can be prepared and know when to jump. The aircraft commander must be quick in making the decision to jump at the earliest possible moment in order to avoid the excessive G buildup which makes escape impossible.

Aircraft out of control develop centrifugal forces of such magnitude that it becomes difficult or impossible to don parachutes, change to walk-around bottles, and reach escape hatches. At 2 Gs, movement is impaired, and at 3½ Gs, a crewmember will find it nearly impossible to move from his position.

Excitement of the emergency increases oxygen utilization.

Certain crewmembers may find it neces-

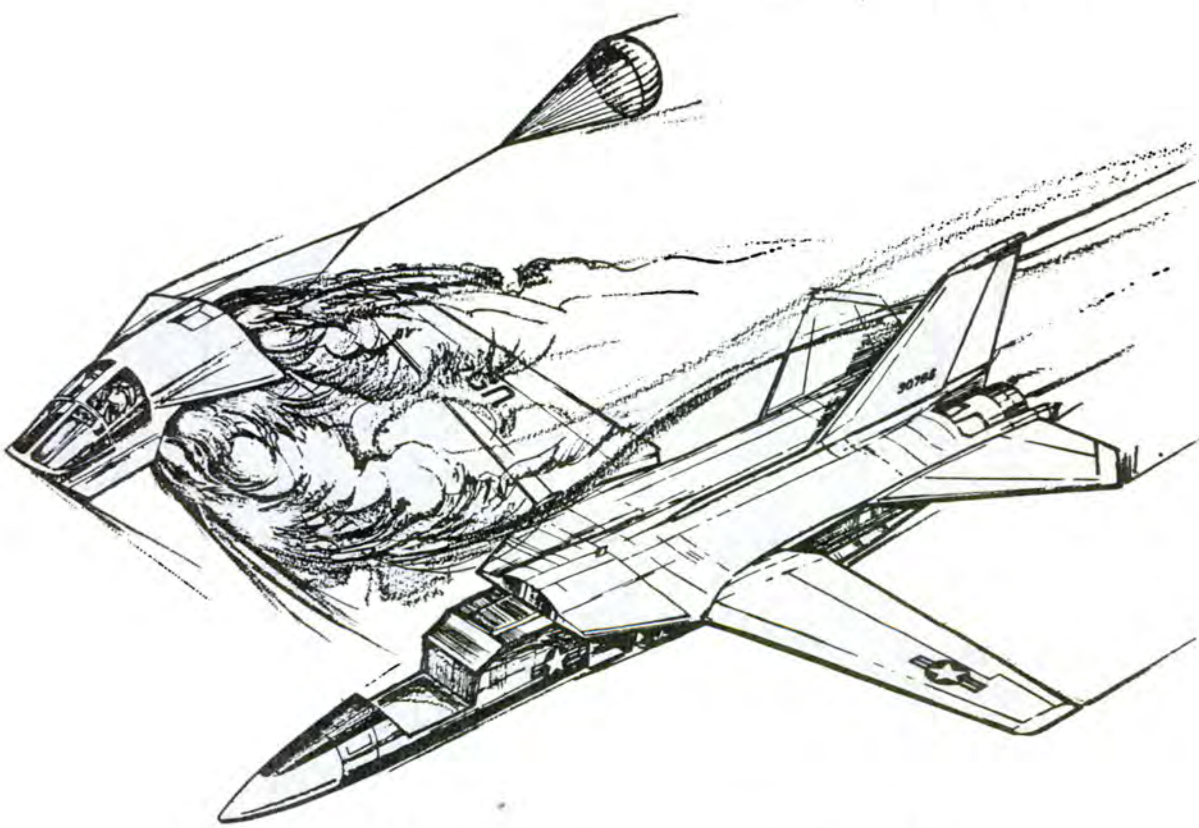
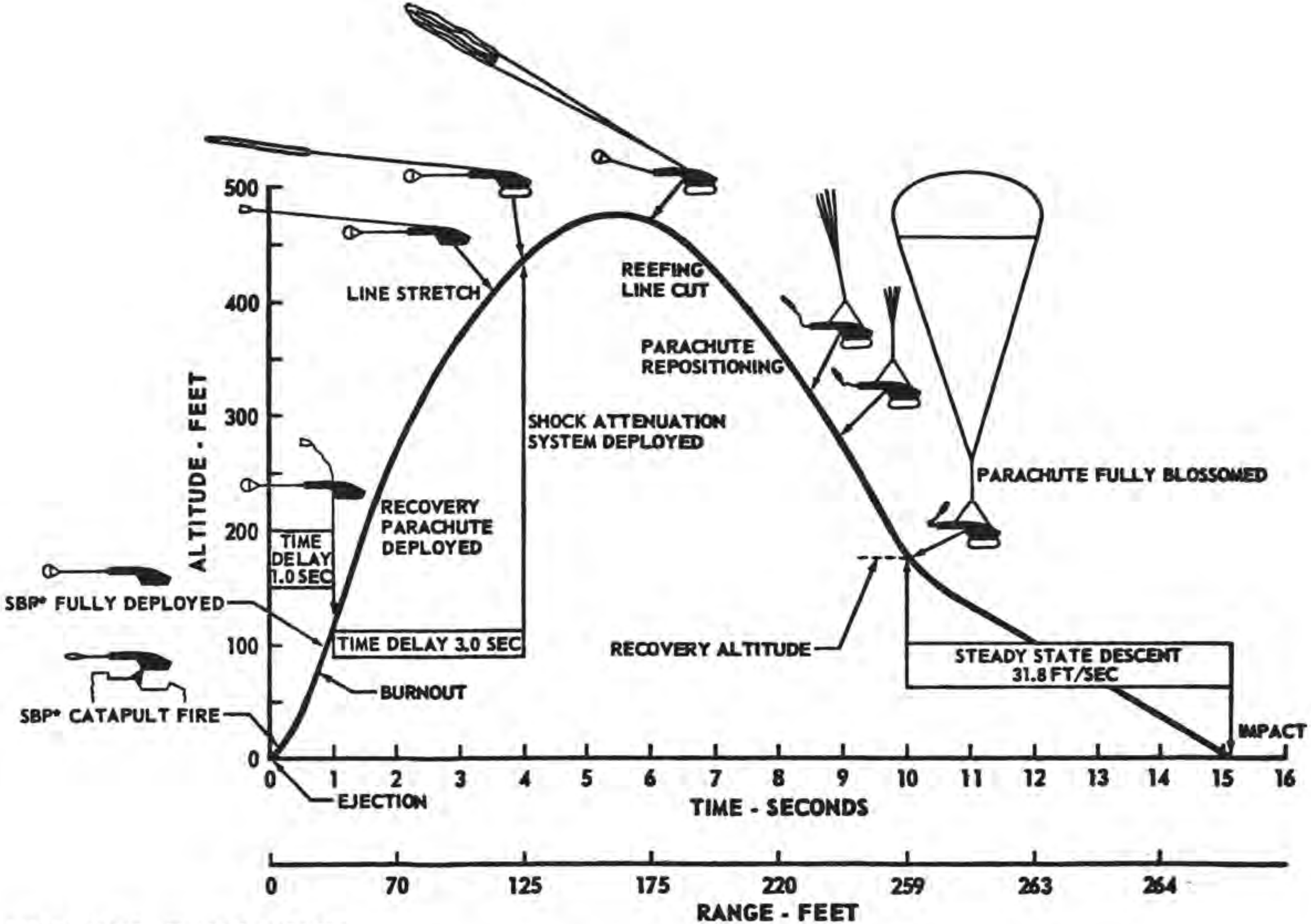


Figure 16–12. F–111 Separable Crew Compartment Escape System.



*STABILIZATION BRAKE PARACHUTE

Figure 16–13. Recovery Sequence for Sea Level Static Ejection of an F–111 Escape System.

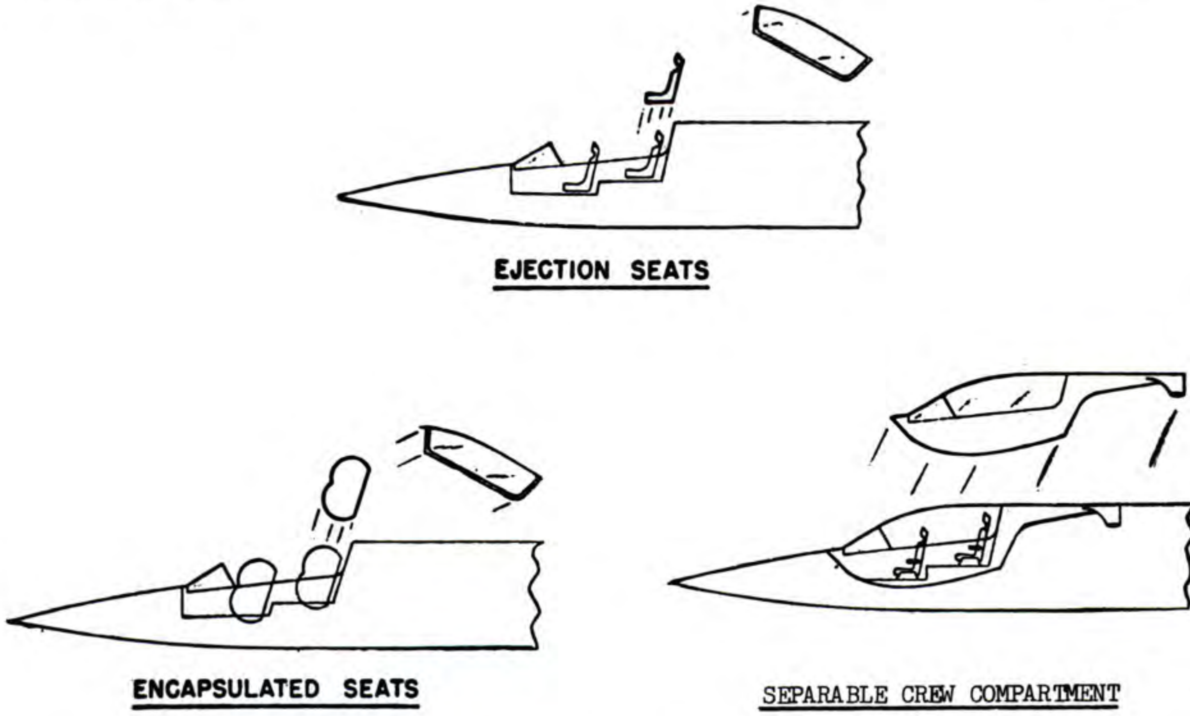


Figure 16–14. Emergency Escape Systems.

sary to use the walk-around bottle (figure 16–15) in reaching distant escape hatches.

The pilot is responsible for the preflight indoctrination of all persons aboard his aircraft, but each man must care for his own chute during flight. All flight personnel should have knowledge of the location of escape hatches, individual aircraft emergency provisions, and bailout procedures, so that escape may be preplanned and accomplished with a minimum of time and effort.

BAILOUT PROCEDURES AND BODY POSITION

Before making an emergency exit from an aircraft, one must be sure that the leg straps of the parachute are tight. For the most part, injuries incurred from opening shock can be eliminated by proper and careful fit of the harness. This factor alone will appreciably reduce sprains, dislocations and fractures of the back, arms, shoulders, and mandible (see figure 16–16).

When the use of the manual parachute release is required and a long free fall is necessary, the best altitude at which to open

Figure 16–15. The Walk-Around Bottle.

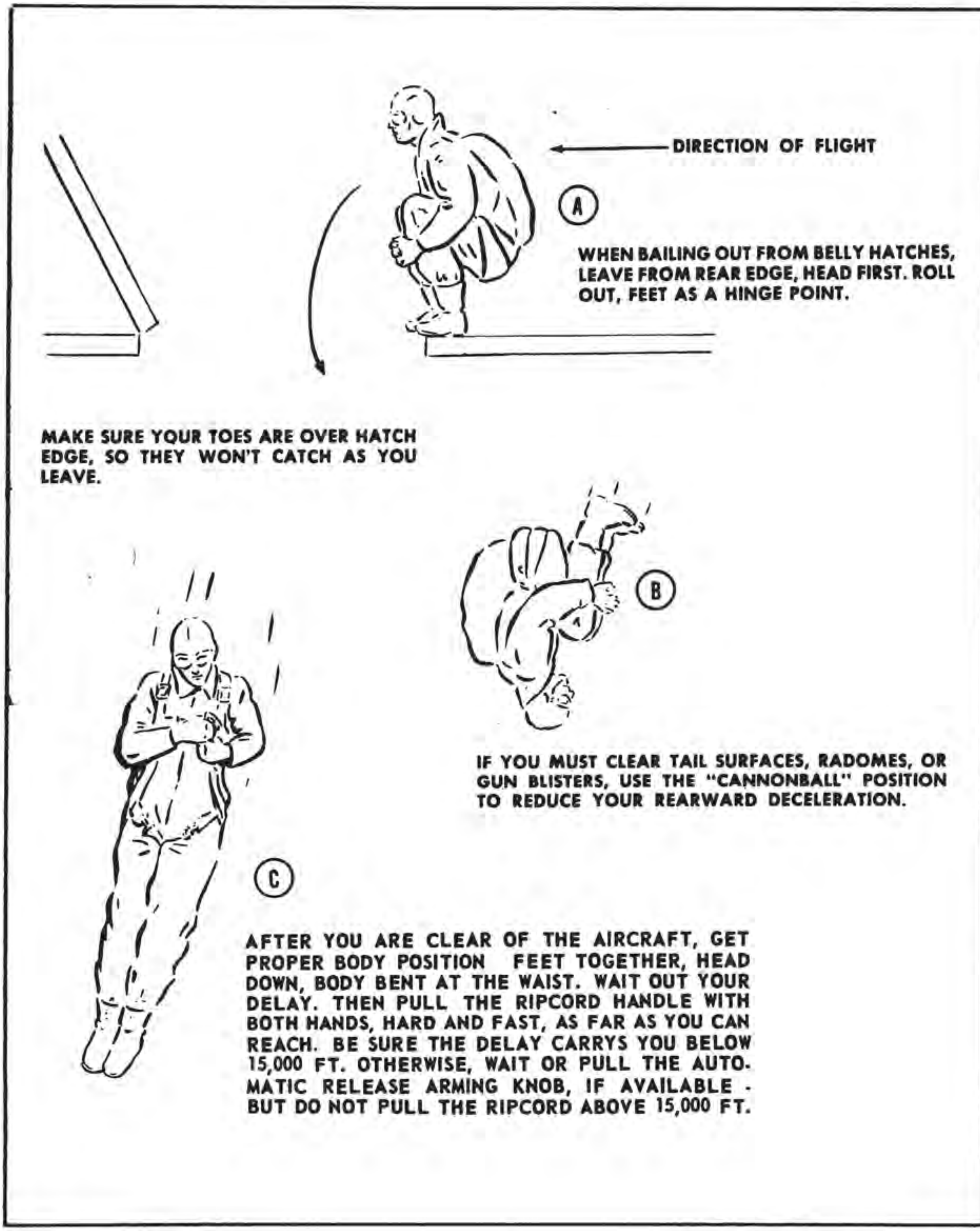


Figure 16–16. Bailout Procedure and Body Position.

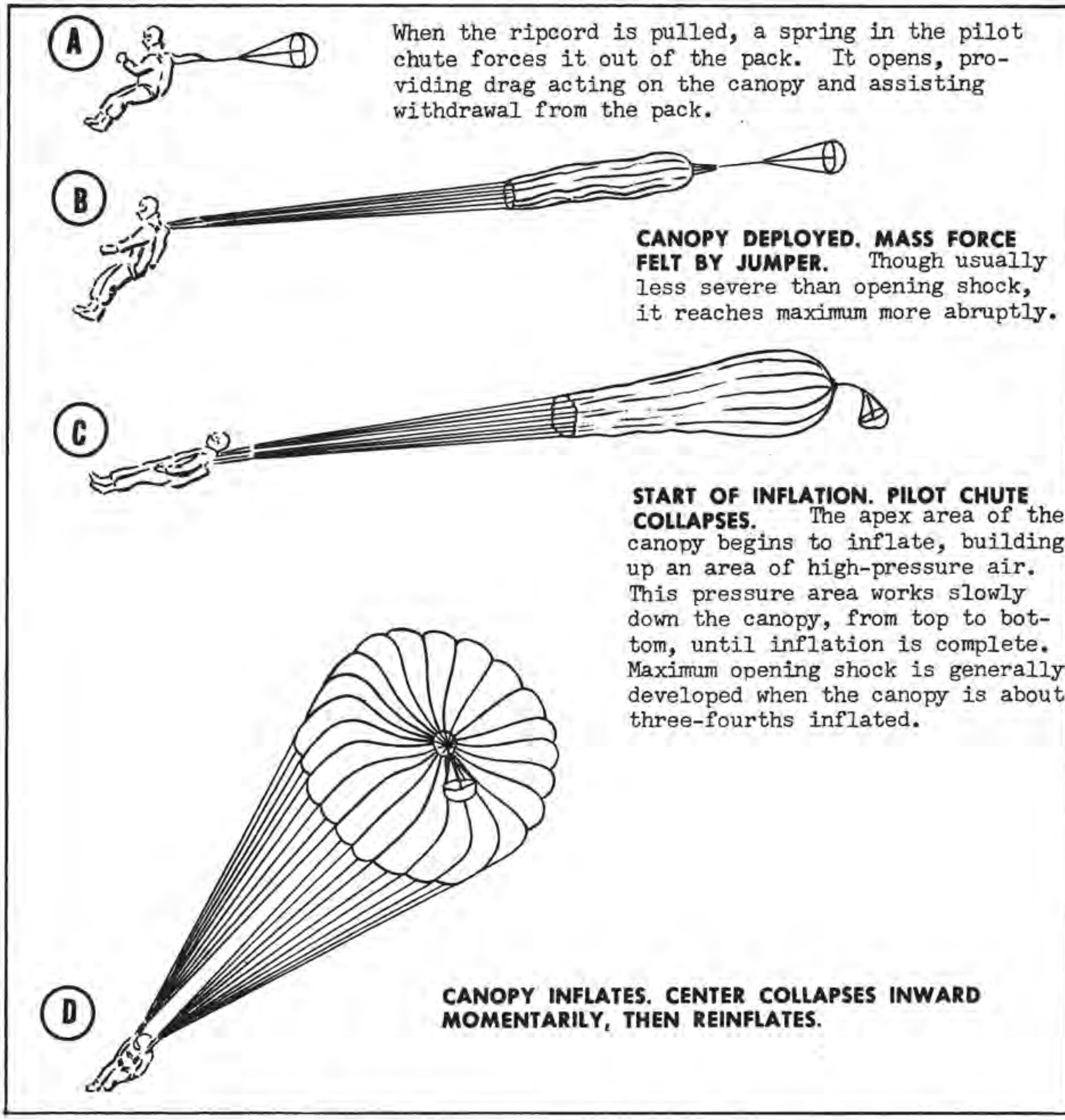


Figure 16-17. Deployment and Inflation of a Parachute Canopy.

the chute is 5,000 feet. At this elevation, the earth becomes green, details can be seen, the horizon spreads rapidly, and the ground begins to rush up to meet the parachutist. This altitude can be estimated easily, and gives the jumper good clearance, warmer air, and sufficient oxygen.

Depending upon speed, altitude, weight, and attitude, a canopy will normally open in 1.5 to 2.5 seconds from the time of ripcord pull. The term "opening time" is the time from ripcord pull to full inflation of the canopy, and is the sum of the deployment and inflation times (see figure 16-17).

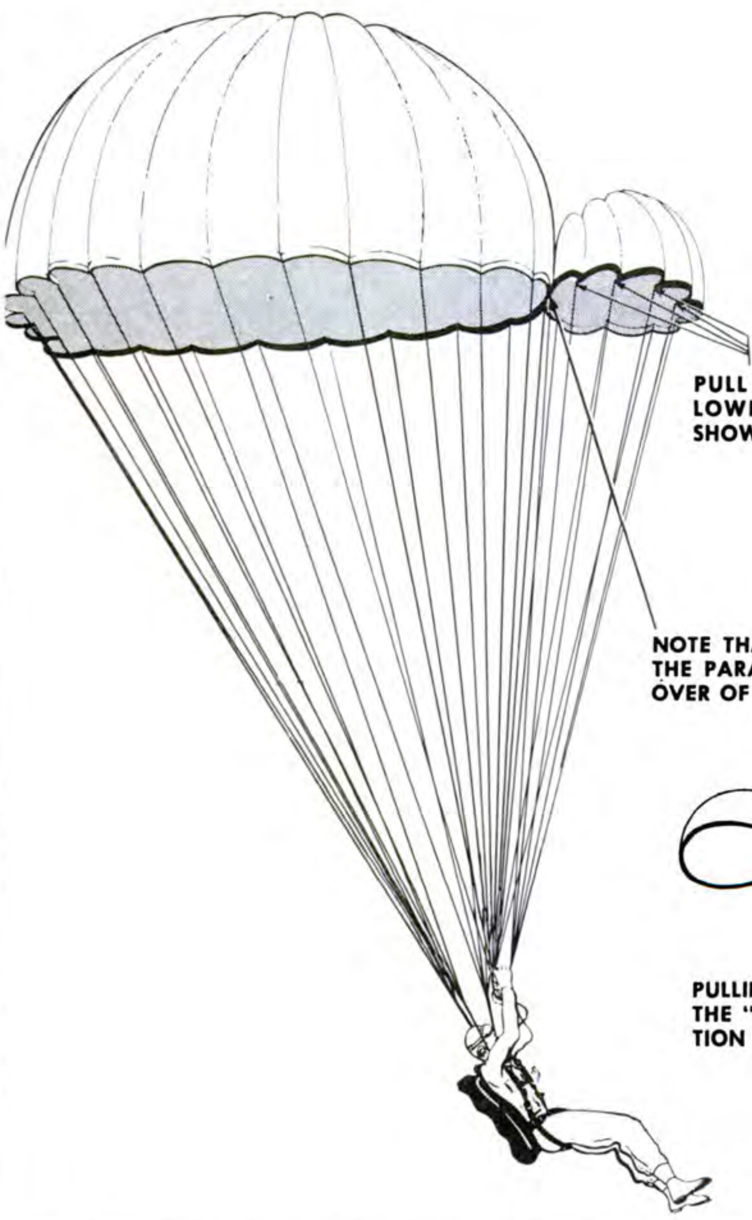


Figure 16–18. An Inversion and the Technique for Removing It From Canopy.

An Inversion and the Technique for Removing It From Canopy

In rare instances, a canopy may inflate with a minor malfunction known as an inversion, line-over, or brassiere opening. If you have an inversion and a few thousand feet of altitude, take a good look at your canopy. You will notice that the skirt of the parachute forms a figure "8." At the crossover point on the "8," one skirt bank will be underneath. If you cannot tell which part of the skirt is lower, just pull down on the suspension lines attached to the smaller loop of the "8." Either method will get rid of the inversion. Very, very rarely, the canopy may be in two equal halves, and look just like a brassiere, hence, the name (see figure 16-18).

Mid-Air Modification for Steerability

This is a method to reduce oscillations and provide a capability for turning and steering the parachute canopy. It is commonly referred to as the "4 line cut." The cutting of four suspension lines (lines 1, 2, 27, and 28) will cause a large "lobe" or "scallop" to form in the rear center portion of the canopy skirt which provides a facility for turning the canopy at the approximate rate of 30 degrees per second, and will also significantly reduce oscillations.

The lines to be cut are marked by small red, fabric identification tapes, and a knife, located on the right front riser, is provided for this purpose (see figures 16-19 and 16-20).

LANDINGS

The following fundamental instructions for landing must be remembered to avoid injury (see figure 16-21).

Normal Ground Landing

a. At 1,000 feet, reach above your head as far as you can comfortably. Grasp both right risers in your right hand and both left risers in your left hand. Make your body turn if required.

b. Look at the horizon. Don't look straight down, because you can't judge distance from this viewing position.

c. Put your feet tightly together, bend your knees slightly, and point your toes so that you will land on the balls of your feet.

d. *Relax.* Prepare to land by letting yourself go limp. (Younger children are rarely hurt in falls because they are limp, so follow their example—*be limp.*)

e. If your body turn was right, you will land, drifting obliquely. Pull down on the risers at the moment of impact. Take the fall by collapsing the way the parachute wants to take you. Don't fight it. Just go limp.

f. The proper sequences for landing the right way are:

On the balls of the feet;
On the side of one leg;

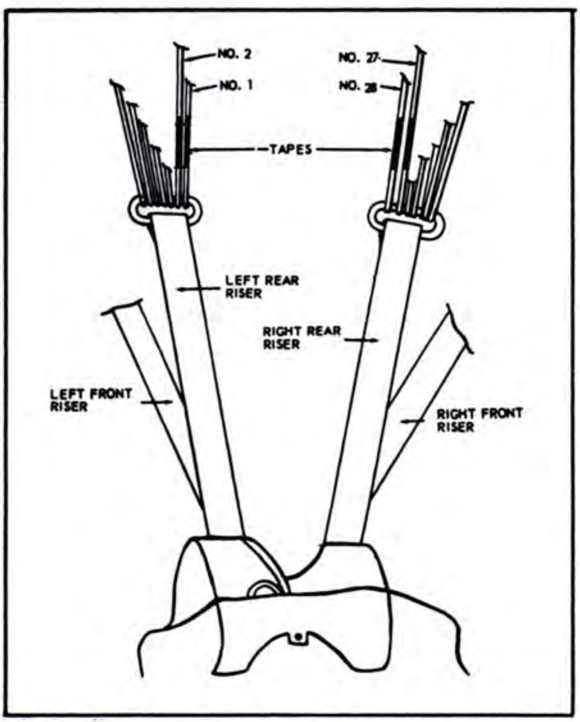


Figure 16-19. Marked Suspension Lines.

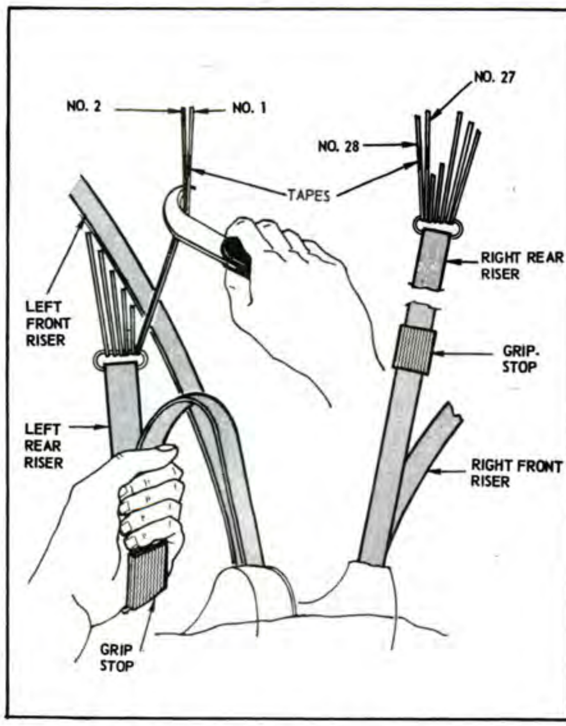
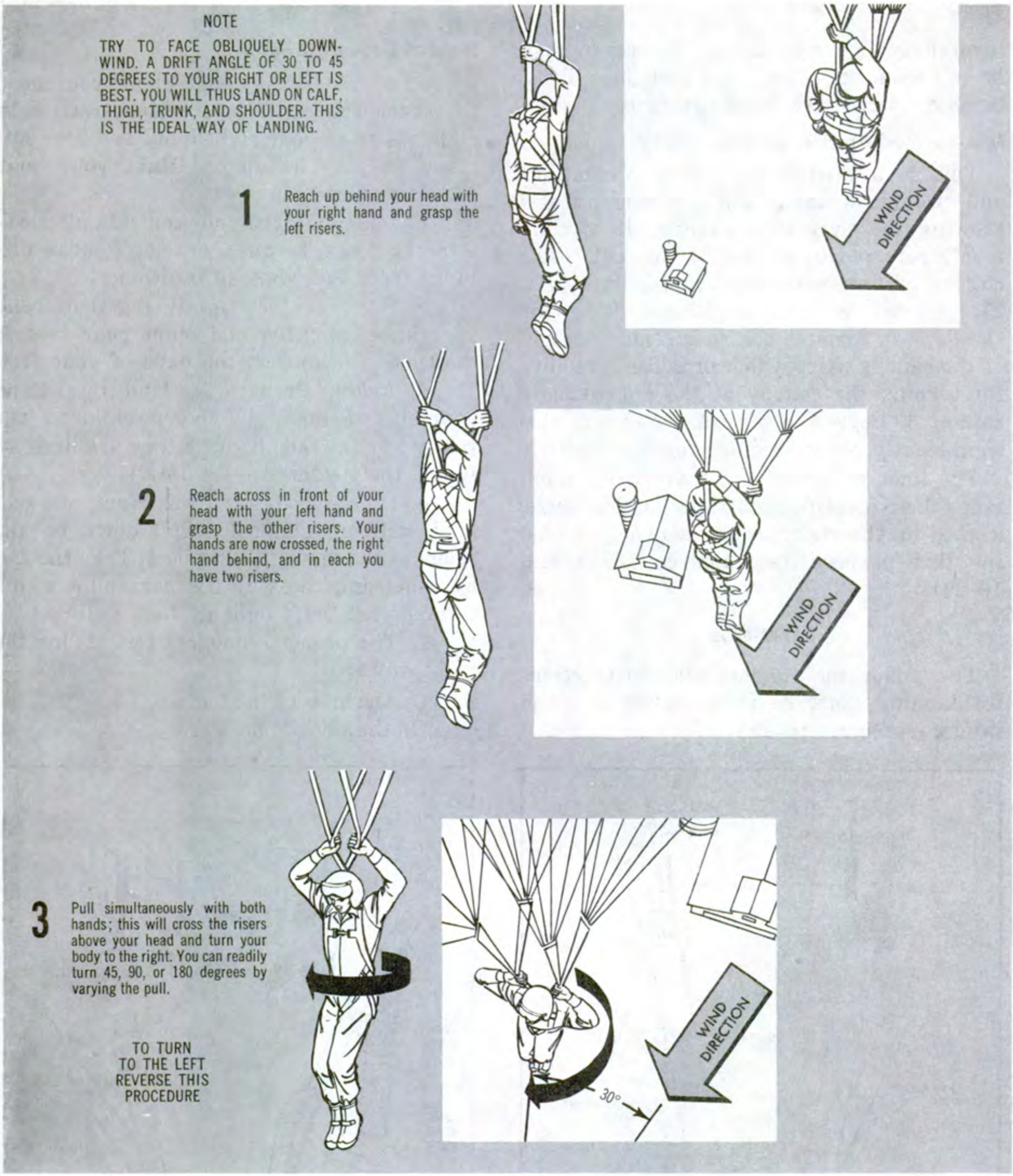


Figure 16-20. Cutting Marked Suspension Lines.



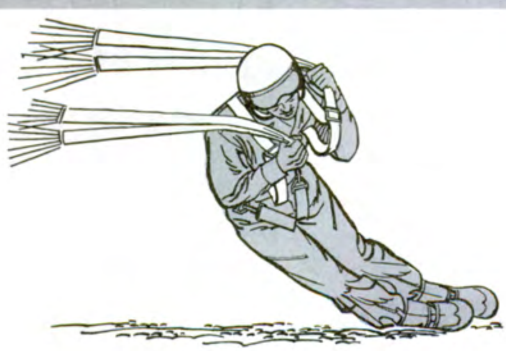


Figure 16–21. The Landing Fall.

On the thigh;
On the hip;
On the trunk; and last,
On one shoulder.

Reading and memorizing the recommended landing fall is a good idea, but will be of minimum benefit unless the technique is practiced and perfected. Practice can be conducted from a low platform (about 4 feet high will do). Practice should include front, back, and side landings. The Army paratrooper landing-injury rate amounts to a small fraction of 1%. In Air Force emergency bailouts, the landing-injury rate is about 4%. An hour or 2 of training may save the pain of a broken limb; in a survival situation, a broken leg may lead to a loss of life.

Wearing the proper footgear is of great advantage in preventing foot and ankle injuries during landings. A jump-type boot affords support to the foot and ankle. This type of boot is advisable for all flying missions other than regular passenger runs. Low-quarter shoes are frequently lost because of windblast or during parachute opening shock, and do not provide proper ankle support upon landing. Furthermore, these shoes are not suitable for extended hiking as would be required during an evasion and escape return trek to a jumper's base.

If there is wind, carry out all normal landing procedures, and immediately after ground impact, release one riser group by operating a canopy release. Use either release, as one is sufficient to spill the canopy.

Landing in Trees

If you are going to land in trees, forget the risers. Cross your arms in front of your face (figure 16–22). Don't try to stop or slow your trip through the trees by grabbing limbs. Bury your face in the crook of an elbow. Keep your feet and knees together. Don't be in a hurry to get down after your canopy hangs up. Rest a moment or two to get over the shock of bailout, and then evaluate your position. Wait for rescue if you can. If you can't, try to make a rope of the risers and suspension lines that you can cut loose. Tie one end to your harness and slide down the rope. Use a hat, handkerchief, or anything available, to keep from burning your hands. Wrapping the line around a leg a couple of times will help you to descend slowly. Don't hurry—you can get painful burns by sliding down the rope too fast. Be extremely cautious about this letdown maneuver unless you have had previous experience. (After safely reaching earth, it would be a shame to kill oneself falling out of a tree.)

Landing in Telephone and Power Wires

(These wires are usually quite high above the ground and several feet apart.) Put your hands over your head with the palms flat against the inside of the front risers. Keep your feet and knees together and toes pointed to avoid straddling a line.

Night Landing

Prepare for a normal landing as soon as the parachute has opened if the night is dark. Be prepared for contact at any time. Surprisingly, statistics show that fewer men are injured in night jumps than in day jumps. The reason seems to be simply that landing is a surprise, and men don't tense up for what isn't expected.

Water Landing

Whether the wind is high or low, the procedures for water landings are the same. While knowing how to swim is a comforting

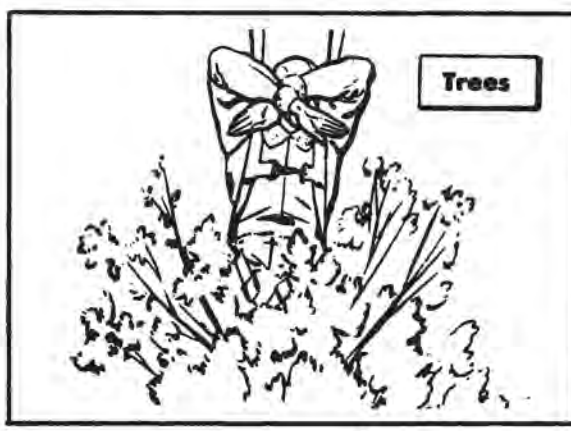


Figure 16–22. Landing in Trees.

assurance, it will not be necessary to expend this extra energy if you are properly equipped and trained.

How the crewman conducts himself in the few minutes after ejection can determine whether or not the ejection will be successful. To prevent a possible fatality after successfully leaving the aircraft, each crewman should fully indoctrinate himself on the procedures set forth below, to the extent that they will become almost automatic when the need for them arises. These procedures are used with a back-type parachute, a seat-type survival kit, and an underarm life preserver, and should be carried out as soon as possible after deployment of the parachute. Following these procedures will reduce the time spent in the water, prevent confusion, conserve strength, and give the crewman time to check his survival gear during parachute descent.

Operation and Procedures. After opening the parachute at 14,000 feet or below, do the following:

a. Check the canopy.

b. Remove the oxygen mask or pressure-helmet visor.

c. Actuate the release on the survival kit to inflate the life raft.

d. Check to insure that the raft has inflated properly. If it has not and time permits, the raft can be pulled up and orally inflated.

e. Inflate the underarm life preserver by pulling sharply downward and slightly outward on the lanyards that extend from the lower front corner of each container. If a failure occurs, the life preserver can be orally inflated.

f. Fasten the front of the cells together by pressing the Velcro (cockleburr) straps together.

g. At an altitude of 1,000 to 2,000 feet over water surface, remove canopy release safety guard.

WARNING

Before attempting to open the clips, insure that the clips have not already been released, as you could be opening the canopy release.

Place the right hand on the right canopy release, if provided, and the left hand on the left canopy release. When the feet touch the water, immediately operate canopy release to spill the parachute. The arms may be crossed when operating the releases. This will prevent the front position of the preserver from coming in contact with the survivor's face upon contact with the water. In any water landing, altitude is difficult to determine. *Do not release the canopy until the feet touch the water, no matter how close you think you are.*

h. After a water landing, entanglement in the suspension lines is probable. If your parachute has only one canopy release, use the hook-blade knife attached to one riser to cut the riser free or to cut suspension lines. (*NOTE:* The hook-blade knife is in a pocket on the riser. Pull the fabric tab to open the pocket. You will find the knife attached to the pocket by a short lanyard. To cut the riser, hold the webbing with one hand and using the other hand, cut the webbing between the point where you are holding the riser, and the shoulder. Do not jerk at the webbing with the hooked blade. A firm slashing motion, similar to that you would use with a straight-blade knife, will cut the webbing easily.) This should be done either before boarding the raft, if conditions permit, or after raft entry. It is recommended that the canopy be discarded rather than retained (as recommended in the past). It may do more harm than good to retain the canopy since the survivor can become entangled in the lines. If land is in sight, however, it may be advisable to retain the canopy since it can be used in many ways on land. If this is not possible, try to retain a number of riser lines and possibly a gore or two from the canopy.

i. To prevent puncture of the raft, close the canopy release safety clips. If the MD-1 kit is used, it is advisable to release one side of the seat pan to prevent its puncturing the raft.

j. Recover the raft by pulling on the life-raft lanyard attached to your kit or seat pan and board by the method most suitable to you.

k. Retrieve the survival kit.

The foregoing procedures should be used day or night after bailout over water, or over land when the possibility exists of drifting over water, or when position is uncertain. If you are certain that you are over land, you may wait and release the kit at approximately 1,000 to 2,000 feet to reduce ground impact. This delay over land may also reduce oscillation. Over enemy territory, it may be advisable not to operate the preserver or raft during parachute descent.

Boarding the Raft:

(1) Pull the raft to you by the lanyard.

(2) Hook the life preserver over the small end of the raft, elevate feet behind you, and pull your body into the raft. By using this method, it may also be possible to swim up into the raft.

(3) Hook the front of the preserver over the raft and pull the raft down until one knee is in the small end.

(4) Turn your back to the small end of the raft and pull the raft under the buttocks.

(5) (Some people have found it easier to board the raft with the cells of the preserver unhooked at the front and pushed aside with the arms.)

(6) During and after boarding, keep the center of gravity of your body low and you will board the raft easier, and even in rough water you will not tip out of the raft.

(7) After boarding the raft, the usual thought is to get rid of the harness. However, you should retain the harness when using the zip-on life preserver (LPU-3/P). Loosen the parachute straps for immediate comfort. Your survival gear is attached to the harness, and removal of the harness may result in loss of this equipment in the event of capsizing. The harness can be used in rescue operations. Therefore, you should first retrieve your equipment container by pulling in the drop lanyard, usually found attached to the neck of the CO_2 bottle, as soon as possible after boarding the raft, to prevent loss. You must insure that the raft and survival gear are securely attached to your person before attempting to remove the harness. Removal can be accomplished by partially deflating one cell of the life preserver, pulling it inside the harness and allowing that side of the harness to slide off. Reinflate the cell orally and repeat for the other side of the harness. Again reinflate the cell when the harness is completely removed.

(8) Use your parachute flares only when you are sure rescue personnel can detect them.

SUMMARY

In summary, the following key points are reiterated for emphasis:

(a) Care for the chute at all times.

(b) Wear the chute while in the aircraft unless it restricts your flight task.

(c) Check the harness fit and preflight of the chute.

(d) Know what a canopy release is, how it operates, and when to use it.

(e) Check the oxygen present in walk-around and bailout bottles.

(f) Be sure your flying helmet fits properly. (Air Force personnel who require a special fitting can be provided this service at Wright-Patterson AFB, Ohio.) (Mail Address: USAF Hosp (HWEAB), Wright-Patterson AFB OH 45433.)

(g) Do not hesitate once the decision for bailout is made.

(h) Clear the aircraft or ejection seat before pulling the ripcord or automatic parachute release arming knob. (When possible, delay at least one second.)

(i) Wait until the terminal velocity is reached, if possible, before pulling the ripcord.

(j) Free-fall to a lower, warmer, and denser altitude.

(k) Separate from the seat as quickly as possible when using the ejection seat.

(l) Practice bailout procedures and become familiar with escape exits.

(m) When making a nonejection bailout, wait until you are clear of the aircraft before pulling the automatic parachute arming knob or ripcord.

(n) Know the attitudes of the body for firing the ejection seat, exiting through escape hatches, opening shock, and landing.

(o) When an over-water bailout is performed and after the parachute canopy is deployed, if at 14,000 feet or below, inflate life raft and life preserver immediately. If CO_2 charge should fail, this will give the jumper adequate time to orally inflate the equipment.

(p) Read the aircraft's flight manual to know how to properly use emergency escape and survival provisions. (These instructions are usually found in section III of each Flight Handbook.)

REFERENCES

The reader should insure the currency of listed references.

Armstrong, Harry G., *Aerospace Medicine*, Chapter 20, Williams and Wilkins Co., Baltimore, Md. (1961).

Technical Order 14D1–2–1, 1 April 1965.

Chapter 17

AEROMEDICAL ASPECTS OF THE AEROSPACE RESCUE AND RECOVERY SERVICE

The Aerospace Rescue and Recovery Service, a subordinate of the Military Airlift Command, is charged with the responsibility to search, locate, afford medical or survival aid, and recover distressed persons or predetermined valuable space hardware on a worldwide basis. Operating from approximately 90 locations throughout the world, the Aerospace Rescue and Recovery Service maintains a daily alert of various highly skilled rescue specialists who meet this challenge. The local flight surgeons who afford medical support to tenant Aerospace Rescue and Recovery Service units have played an important part in many successful rescue missions.

History of Rescue in the Air Force

The need for an organized rescue effort was recognized in the Battle of Britain during World War II, when it was evident that many "downed" fliers could be retrieved from the English Channel with boats and seaplanes using systematic communications, search, location, and recovery techniques. US Forces formed several Air Rescue Squadrons whose primary mission was to save lives and thus minimize the loss of expensively trained professional aircrewmen. The need for the conservation of specialized manpower, which was, and has continued to be, a subject of prime importance, and the morale and confidence boosts gained by aircrews through knowledge of the rescue effort, stimulated the continuation and expansion of this program.

These squadrons were trained to perform aerial and surface rescue operations in all areas of the world and under all climatic conditions. They were originally placed under the control of the respective theater commander, to be employed in support of a rescue mission as he directed. The termination of hostilities in World War II gradually brought all of these rescue forces into a unified Air Rescue Service, which was a subordinate command of the Military Air Transport Service.

Further expansion of the rescue mission by the helicopter and longer range fixed-wing search aircraft gradually occurred. The need for trained combat aircrew recovery units, using specialized equipment, techniques, and aircraft, grew from experiences in Korea and Vietnam. The requirement to afford contingency recovery support for our manned space program and primary recovery responsibility for many unmanned and hardware recovery space missions, dictated a need for greater proficiency in all areas. Extensive familiarity with specialized tracking equipment, spacecraft egress systems, toxicity of rocket propellants, and techniques for the aerial delivery and installation of space capsule flotation collars became mandatory. The acquisition of this expanded mission responsibility led to the new designation, Aerospace Rescue and Recovery Service.

Organization

The Aerospace Rescue and Recovery Service is structured from a command headquarters through five Aerospace Rescue and Recovery Centers to Aerospace Rescue and Recovery Squadrons and Local Base Rescue Detachments. The headquarters of Aerospace Rescue and Recovery Service exercises command jurisdiction, administrative supervision, and technical control of all field rescue activities. It represents the standardization authority for rescue and recovery procedures, insuring that these procedures are accomplished in the same manner on a worldwide basis. It also maintains direct control of four rescue squadrons affording a capability for immediate operational response and mission flexibility.

The Aerospace Rescue and Recovery Center represents an extension of the headquarters that exercises direct supervision and control of rescue and recovery operations within a specific geographic area. An elaborate communication network enables the Center to control and coordinate an effective and rapid search and rescue mission, using not only the forces of the Aerospace Rescue and Recovery Service, but also those of the US Coast Guard, Army, Navy, Marine Corps or Civil Air Patrol, and, on occasion, those of other nations.

The Aerospace Rescue and Recovery Squadron is the workhorse for the worldwide search, locate and rescue mission. Equipped with long-range, fixed-wing aircraft, it also provides the contingency landing area coverage for the manned space program. The Local Base Rescue (LBR) units are detachments of the Aerospace Rescue and Recovery Centers. They are equipped with rotary-wing aircraft and are strategically located at both CONUS and oversea air bases to provide prompt short-range rescue and recovery of personnel involved in aircraft/missile accidents or incidents, and to participate in medical evacuation and civilian disaster support missions. Additionally, they provide an emergency fire suppression crash rescue capability by using an air transportable fire suppression kit and expeditious use of helicopter rotor downwash. Operational control of the LBR is retained by the local base commander (see figure 17–1).

Equipment

Any portion of the worldwide military or civilian communication network may be used for the notification and coordination of rescue missions. A variety of aircraft are available to support a rescue effort ranging from long-range, fixed-wing search planes through fixed-wing amphibians to both intermediate and short-range helicopters. The addition of surface-to-air and air-to-air retrieval systems to the fixed-wing aircraft and the mid-air refueling capability to the helicopter will extend rescue and recovery potential to all areas of the world.

Pararescue

The Aerospace Rescue and Recovery Service pararescueman is a vigorous, highly motivated, rescue specialist, trained to enter any disaster area, regardless of location, by the most practical method, using parachute, surface or helicopter transport. He is a precision parachutist, qualified SCUBA diver (equipped to parachute with SCUBA into any body of water), survival specialist, and emergency medical care technician, and is proficient in current techniques for spacecraft and combat aircrew recovery. The pararescueman exists primarily to deliver competent, semiprofessional emergency medical care and survival knowledge to distressed persons in any geographic location. He has been required to provide this care for up to 48 hours, when immediate casualty evacuation was not practical. Through direct radio communication he can represent an extension of a physician's hands to render aid at a remote disaster site.

Operation of a Rescue Mission

Alert. If a communications search is being made or a distress transmission is received by an appropriate flight-following agency, normally, the Aerospace Rescue and Recovery Service is notified. When the result of this communications search is negative, the flight-following agency declares the aircraft overdue.

Search. Upon receipt of a distress transmission or "May Day," the closest rescue aircraft are immediately launched to intercept the position of the distressed aircraft. Following receipt of an "overdue aircraft" message, the Aerospace Rescue and Recovery Service unit involved initiates action to conduct an extended communications search by contacting all facilities not served by normal

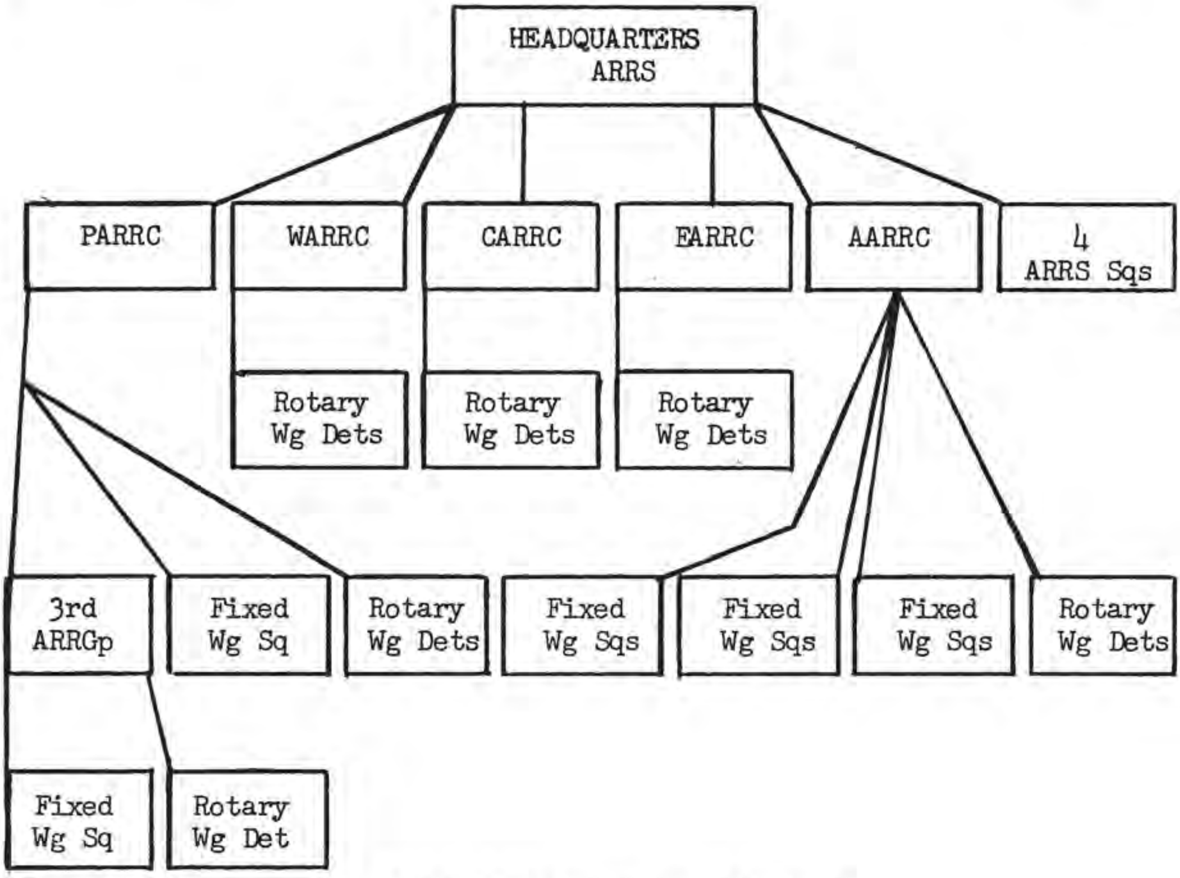


Figure 17–1. ARRS Organizational Structure.

flight service or Federal Aviation Administration (FAA) communications systems. An aircraft is declared missing when the result of this extended communications search is negative and predicted fuel exhaustion time is reached. When the aircraft is reported as "missing" or is known to have crashed, rescue aircraft are dispatched to search the most probable area. The rescue mission commander will assign individual search areas to the Rescue Crew Commander (RCC) of each aircraft participating in the mission.

Rescue. Once the disaster site is located, the commander of the first arriving rescue aircraft becomes the On-Scene Mission Commander. He will determine how the rescue will be effected, using his extensive rescue knowledge and training background. Access time, remoteness or hostility of the disaster site, area resources available, and the existence of survivors will guide his decision to deploy pararescue, helicopter or surface recovery forces.

Flight Surgeon's Role and Responsibilities in the ARRS Mission

Each member of a rescue aircrew is a highly trained professional in his individual job. Rescue or recovery missions that may require professional medical care or advice necessitate that the local Flight Surgeon become an integral part of the rescue team. His assessment of the medical urgency of a particular situation for the rescue unit commander often will determine the need for or type of mission to be conducted.

One rated Flight Surgeon, who is also a qualified paraphysician on parachute status, is assigned to Headquarters, Aerospace

Rescue and Recovery Service. In addition to supervising an Aerospace Medicine Program for all rescue personnel, he is responsible for the various medical training programs and the standardization and development of medical equipment and techniques used by Aerospace Rescue and Recovery Service pararescuemen.

The local base Flight Surgeon or Flight Medical Officer assigned to support a rescue unit is requested to insure that his rescue personnel (aircrew and maintenance alike) are proficient in first aid and are knowledgeable in the pertinent aspects of preventive medicine, occupational health, and field sanitation. In addition, he is called upon to conduct continuing medical training for the pararescuemen on a recurring basis. The following is an abbreviated outline of the emergency medical care instruction required:

PARARESCUE MEDICAL TRAINING

I. Recognition and Treatment of Respiratory Distress
  A. Signs and symptoms
  B. Treatment emphasizing resuscitative procedures
  C. Special considerations—the various chest injuries
II. Shock
  A. Types
  B. Symptoms and clinical signs
  C. Principles for general and specific therapy
    1. Venipuncture technique
    2. Fundamentals of fluid replacement
    3. Adjunctive drug therapy—vasopressor
III. Control of Hemorrhage and General Principles of Wound Care
  A. Methods for hemorrhage control
  B. Wound care
    1. Basic debridement procedures
    2. Aseptic technique under field conditions
    3. Suture techniques
    4. Management of the contaminated wound
  C. Drug therapy consideration
    1. Antitoxin and toxoid usage
    2. Antibiotics
IV. Thermal Injury
  A. Burns
    1. Identification of types and degree
    2. Rule of Nines
    3. Therapy
      a. Shock
      b. Suppression of contamination
      c. Fluid replacement—Brooke Army Hospital Formula
      d. Principles for administration of sedation, analgesia, and antibiotics
  B. Cold injury
    1. Types
    2. Therapy
V. Fractures
  A. Identification of various clinical types
  B. Therapy
    1. Principles and methods of immobilization
    2. Care of the compound fracture
    3. Management of the traumatic amputation
VI. Head Injuries
  A. Diagnosis
  B. General guidelines for initial clinical management
    1. Need for continuous record of patient's condition
    2. Airway procedures
    3. Principles governing judicious use of sedation and analgesia
    4. Indications for use of systemic antibiotics
  C. Signs and symptoms of increasing intracranial pressure
VII. Spinal Injuries
  A. Diagnosis
  B. Proper methods of patient transport
  C. Principles governing use of sedation and analgesia
  D. Problem of urinary retention and procedure for urethral catheterization
VIII. Ocular Injuries
  A. Guides for assessment of injury
  B. Emergency therapy

IX. Basic Principles for the Management of an Uncomplicated Obstetrical Delivery

This curriculum is designed to give the pararescueman a complete medical training review in each 12 calendar-month period. A minimum of 24 formal training hours should be allocated for its completion. The outline may be divided to assign 4 hours every 2 consecutive months for the completion of each of the first five sections (I through V). The remaining sections (VI through IX) may be combined in the 4-hour period allocated to the final 2-month interval.

The comprehensive pararescue medical training guideline is published in Air Rescue and Recovery Service Manual (ARRSM) 55-1. Also, a complete listing of all medical equipment contained in the pararescue medical/jump kit is specified in ARRSR 167-1. Through close contact with the pararescueman and his local rescue unit's operation, the Flight Surgeon can make full and better use of the Aerospace Rescue and Recovery Service medical and rescue capability—"That Others May Live."

AEROMEDICAL ASPECTS OF SURVIVAL

The survival training and personal equipment familiarization programs of the Air Force must represent more than an academic exercise in selfpreservation to the physician. Naturally, the personal benefit derived from any survival training program is a positive psychologic background of security and self-confidence. The Flight Surgeon and other aircrewmen who, through training experiences, have been afforded exposure to many of the problems of a simulated survival situation, become mentally confident that they will be able to overcome these problems and survive. However, the Flight Surgeon and other Air Force medical officers should have a deeper interest in the survival training and personal equipment familiarization and development programs. The physician must insure that his unit aircrew are knowledgeable and proficient in first aid and capable of caring for themselves and other survivors. The aircrewman must also be familiar with the basic principles of survival medicine if he is to make the utmost use of survival kit items and thus protect his own well-being. Minor illnesses may become major problems in a survival situation.

Achievement of the proper psychological attitude for survival is probably the most important single factor. A person's fear and anxiety may be the greatest hazard in a survival situation. Fear will destroy man's ability to cope with problems in an intelligent manner. Those who make an emergency descent into strange terrain usually experience some "mental shock" or confusion which is the resultant of fear of the unknown, indecision, the experience of initial bailout, and the inability to organize a sensible plan of action. If a combat or hostile environment exists, this confusion state is usually magnified. Persons who, in the past, have been exposed to simulated survival situations, will rally in a short time. Those who have not been prepared will react slowly and in a disorganized manner, and are likely to jeopardize their prospects for survival and rescue.

Precautionary Survival Procedures

Survival kits and equipment must be appropriate for the area of mission operation (climate, geography). They must be readily available to flying personnel and they must be checked daily and inspected at scheduled intervals to make certain that individual items are not missing. Survival kits not worn on the person must be properly stowed aboard the aircraft. They should be secured in a manner that will permit rapid availability and removal. In large aircraft, they should be distributed in several locations.

Where possible, clothing, shoes, and equipment appropriate to ground survival in the area should be worn in flight. In flights over arctic areas, the wearing of heavy clothing necessitates keeping the interior of the aircraft sufficiently cool to avoid perspiration and overheating. Under some circumstances, as when the full pressure suit is worn or when flight missions are over both hot and cold temperature extremes, clothing appropriate for ground conditions cannot be worn. In these cases, supplemental clothing should be carried in survival kits.

Flying personnel should be trained in the use of their survival equipment as applicable to the areas covered by their missions. A single briefing is not satisfactory. Demonstration to and active participation by aircrew personnel in the use of all items of personal equipment are highly recommended. Participation by flying personnel in water, arctic, jungle, and desert survival training at schools conducted by the Air Force and the various commands is a highly desirable goal. Applicable training films are listed in AFM 64-5. In addition to normal preflight briefing on the availability and use of survival equipment, the Flight Surgeon, working with the unit survival training and equipment officer, should monitor and participate in periodic realistic refresher survival training to ascertain whether the training and equipment are adequate for the unit mission.

Personal Equipment

Frequent visits to the personal equipment section will afford the Flight Surgeon first-hand knowledge of all survival and personal equipment items available to his aircrews. He should review the various medical items contained in the kits to insure that they are adequate and timely for current mission support. Only when the Flight Surgeon is familiar with the survival and personal equipment needs of his aircrews can he intelligently initiate requests for the deletion of unnecessary items or the development of more compact and effective products.

AFSC System Program Office (SPO), Life Support System 412A

The AFSC System Program Office (SPO), for Life Support System (LSS) 412A, at Wright-Patterson AFB, Ohio, was established to meet the requirements of Specific Operational Requirement (SOR) 218 for a life support system, dated 28 August 1964. This Life Support SPO has assumed the functions of the former USAF Personal Equipment Advisory Group (PEAG) as a developer and monitor of personal and survival equipment.

The Life Support SPO is a centralized agency responsible for the development, standardization and integration of skills and techniques required to equip aircrews with the best possible functional and emergency/survival equipment. The objective is to enable the aircrewman to become a part of his weapon, to remain functional in its environment, and to sustain himself in an emergency/survival situation in any global environment.

The fields of survival and personal equipment are so broad and varied that additional reading is mandatory for their complete treatment. Principles for survival, current techniques, and the proper use of all available survival equipment are most effectively discussed in AFM 64-5. The subject of survival education is well stated in AFM 64-3, and there is a detailed account of available personal equipment for all types of aircraft and mission support in AFM 64-4. Most Flight Surgeons read and digest AFM 64-5 several times. It is interesting, informative, well-written, and, most of all, contains information and ideas on the essentials for selfpreservation.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., Escape, Survival and Rescue, Chapter 20, *Aerospace Medicine*, Baltimore, Williams and Wilkins Co. (1961).

AFM 2-36, *Search, Rescue, and Recovery Operations*.

AFM 64-2, *National Search and Rescue Manual*.

AFM 64-3, *Survival—Training Edition*.

AFM 64-4, *Handbook of Personal Equipment*.

AFM 64-5, *Survival*.

AFM 64-6, *Aircraft Emergency Procedures Over Water*.

AFM 64-15, *Survival Uses of the Parachute.*

AFR 23-19, *Aerospace Rescue and Recovery Service (ARRS).*

*ARRSM 55-1, *Aerospace Rescue and Recovery Service Operations Manual.*

ARRSR 167-1, *Medical/Jump Kit for Pararescue Personnel.*

Arctic, Desert, Tropic Information Center Publications:

- A-107 *Man in the Arctic—The Changing Nature of His Quest for Food and Water as Related to Snow, Ice, and Permafrost.*
- D-100 *Afoot in the Desert.*
- D-102 *Sun-Sand and Survival—An Analysis of Desert Survival Experiences During WW II.*
- D-104 *The Desert Survival Field Test.*
- G-104 *Airmen Against the Sea—An Analysis of Sea Survival Experiences.*
- G-105 *Analysis of Survival Equipment.*
- G-107 *Water Survival Field Tests.*
- G-110 *Annotated Bibliography of Survival, Series 1.*
- G-110A *Annotated Bibliography of Survival, Series 2.*
- G-110B *Annotated Bibliography of Survival, Series 3.*
- G-110C *Annotated Bibliography of Survival, Series 4.*
- G-111 *Survival on Film.*
- G-112 *Cold and Wet—Estimated Survival Time in Global Waters.*
- T-100 *999 Survived—An Analysis of Survival Experiences in the Southwest Pacific.*
- T-101 *The Jungle Survival Field Test.*

Information Bulletins:

1. *Sharks.*
2. *Poisonous Snakes of North America.*
3. *Poisonous Snakes of Central and South America.*
4. *Poisonous Snakes of Europe, Africa, and Near East.*
5. *Poisonous Snakes of Southeastern Asia.*
6. *Poisonous Snakes of Australia, New Guinea, and the Pacific Islands.*

* Not available through HQ USAF PDOs.

Chapter 18

PRESSURE SUITS

Aircraft capable of ascent to high altitudes are equipped with cabin pressurization systems and oxygen systems that keep crewmen well oxygenated at safe cabin altitudes. If cabin pressurization fails, as it may and often does under a variety of conditions, or if an operational capsule is not provided, the crewmen are rapidly exposed to ambient pressure and are totally dependent on the aircraft oxygen system for life support. At cabin altitudes below 50,000 feet, pressure demand oxygen systems generally will maintain safe physiological states long enough to enable the aircrewmen to take corrective action. However, at altitudes above 50,000 feet, even pressure demand oxygen equipment is insufficient to prevent acute hypoxic failure and resultant inability to take effective corrective action.

The survival of man exposed to this hostile environment of low pressure altitudes above 50,000 feet requires that oxygen pressure be provided to the lungs with necessary counterpressure on the outside of the body to prevent pooling of body fluids and subsequent collapse. The required counterpressure can be provided to the body mechanically, pneumatically or by a combination of both. The conventional methods used to provide counterpressure are shown in figure 18-1. The first method shown uses an expansible pneumatic tube (capstan) around which multiple webbings are looped. These webbings are attached to a fabric which fits snugly on the body or extremity. When the tube is filled with gas, it expands and pulls the webbings, thus applying a mechanical pressure to the body. The tube size and pressure can be varied to provide the desired counterpressure to the body. The second method uses a flattened pneumatic tube or bladder that is placed next to the body under a fabric which incloses both the body and the tube. When the tube is filled with gas, it expands and pressurizes the body over which it is placed and mechanically tightens the fabric on the remainder of the body surfaces not covered by the tube. The tube size and pressure can be varied to provide the desired counterpressure to the body. The third method uses a double-walled pneumatic bladder that incloses the body completely. When the bladder is filled with gas, it expands and applies direct pressure through the inner layer of the bladder to the body. A restraint fabric is used over the outside of the bladder to prevent excess ballooning. The fourth method uses a single-walled pneumatic bladder that incloses the entire body. When gas is introduced between the bladder layer and the body, the body is pressurized directly by the gas. The outside of the bladder is restrained from excess ballooning by an overlying fabric restraint layer. The pressure can be varied directly to apply the desired counterpressure. The first three methods are commonly referred to as partial pressure methods and the fourth as a full pressure method.

The pressure suit concept was first advanced by J. S. Haldane, an English respiratory physiologist, in 1920. Thirteen years later, the first such garment was constructed in England for an American balloonist. This suit successfully protected him in a low pressure chamber flight to 85,000 feet for 30 minutes. By 1940, at least five nations, including the United States, had constructed and operated pressurizing garments to be worn on high altitude flights. The early suits were heavy, restricted body motion, exerted severe thermal stresses on their wearers and,

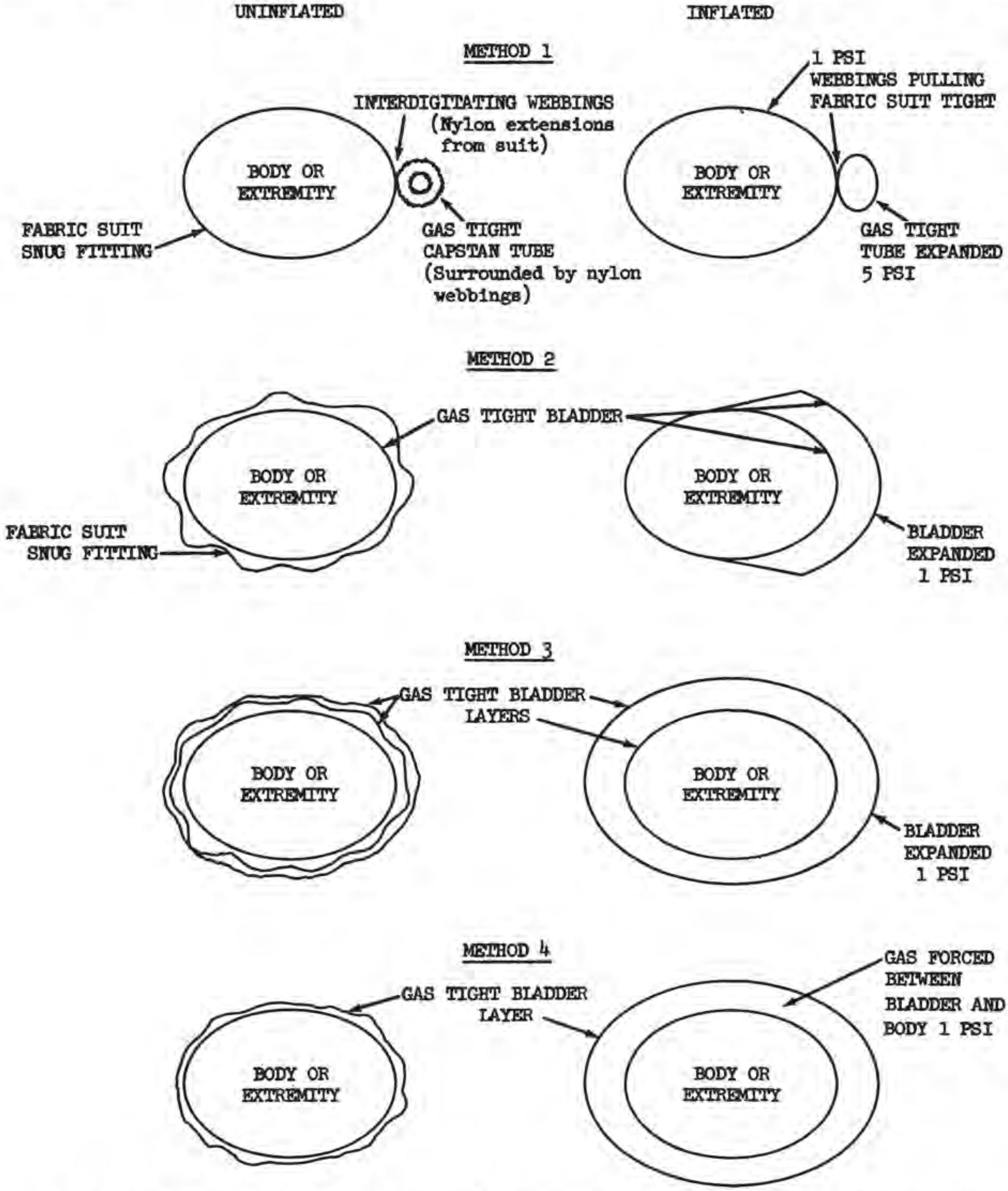


Figure 18–1. Conventional Counterpressure Methods—Cross Section Through Body or Extremity.

as a result, constituted a hazard to safe flying. By the late 1950's, pressure suit prototypes of the present systems appeared feasible. These suits incorporated one or more of the four methods previously mentioned, and helmets that delivered oxygen breathing gas and counterpressure for the head and neck. The source of oxygen came from the aircraft or an emergency supply.

Continuous development of each of these systems has resulted in the current MC–3A and MC–4A partial pressure suit assemblies (see figure 18–2); the CSU–4/P bladder suit assembly (see figure 18–3); the A/P22S–3 (see figure 18–4); and A/P22S–2 (see figure 18–5) full pressure suit assemblies. Further improvements and the possible development of new concepts will provide continued development change in the future.

CAPSTAN PRESSURE SUITS

The capstan suit assembly consists of a helmet, coverall and gloves. The helmet seals at the neck and is pressurized with 100% breathing oxygen from the regulator. Visor fogging is prevented by a laminated heating element in the visor. The helmet is also equipped with earphones and a microphone. The coverall protects the remainder of the body except for the hands and feet. Pressurized gloves protect the hands. A tailored bladder (see figure 18–1—method 3) covers the chest and abdomen including the axillae, groin, and upper thighs. An outer tight-fitting inelastic nylon fabric prevents ballooning of the torso bladder and is continued over the four extremities to form the sleeves and legs. The capstan system provides effective mechanical pressurization of the extremities (see figure 18–1—method 1). As noted in figure 18–1, the capstan system can be described as a two-loop system shaped like the figure "8." One loop incloses the limb and the second incloses an expansible gas tube. Inflation of the gas tube increases the diameter of the capstan loop at the expense of the limb loop, exerting a force to pressurize the limb. The MC–3A and MC–4A pressure suits are so designed that the capstan diameter at any point is about one-fifth of the limb diameter at that point. Therefore, capstan pressures are five times as great as the desired applied limb pressure. *For example,* at 50,000 feet (87 mm Hg), the suit delivers 54 mm Hg pressure to provide a body altitude of 40,000 feet (87 mm Hg + 54 mm Hg = 141 mm Hg). Bladder and helmet pressures measure 54 mm Hg, but capstan pressure is 270 mm Hg (54 mm Hg × 5). Because of the 5:1 capstan to limb pressure

Figure 18–2. High Altitude Pressure Suit—Type MC–3A With Type MA–2 Helmet and High Altitude Gloves.

Figure 18–3. CSU–4/P Bladder Pressure Suit With HGU–8/P Helmet and MG–1 Gloves.

Figure 18-4. A/P22S-3 Full Pressure Suit.

ratio, the actual pressure experienced by the limbs is only 54 mm Hg. The capstan suit regulator is a device which provides for appropriate breathing oxygen pressures, bladder pressures, and capstan pressures to give physiological protection at altitude.

The MC-4A pressure suit is equipped with a built-in G garment to protect against positive G's. Protection against positive G requires pressurization of the abdomen and lower limbs independent of the whole-body pressurization offered by the suit alone. The capstan system provides a high degree of reliability. Properly fitted aircrew members have remained at simulated altitudes of 100,000 feet for as long as 5 hours without demonstrable physiological deficiencies. Naturally, such long exposures require proper preflight denitrogenation and a very good suit fit.

High altitude gloves, type MG-1, are provided for use with the capstan pressure suits if required by the mission duration. These gloves have an outer layer of leather with an inner partial bladder (figure 18-1—method 2) for a counterpressure device. The bladder pressure in the gloves is equal to that in the suit bladder from which gas is supplied.

BLADDER PRESSURE SUIT

The CSU-4/P suit assembly consists of a helmet, a coverall (containing a continuous bladder which covers the torso including the legs and arms) and separate gloves pressurized by gas from the bladder system. There is an inner ventilation layer beneath the bladder. An outer restraining layer prevents ballooning. Ballooning must be minimized in all pressure suits since the consequent change in shape and size not only decreases suit mobility but may also cause the inflated garment to bind on cockpit structures. The garment is equipped with three zippers, enabling a trained flier to don the ensemble in 1 or 2 minutes, giving rise to the name "quick don" suit.

The helmet is constructed of fiberglas with a clear plastic visor for good visibility. A sunshade is also provided. A neck seal around

Figure 18-5. A/P22S-2 Full Pressure Suit.

the lower edge of the helmet neckpiece allows containment of breathing oxygen in the helmet. A microphone and earphones complete the helmet assembly.

The bladder pressure suit maintains the wearer at an altitude of 40,000 feet (141 mm Hg). The wearer, breathing 100 percent O_2, is therefore at an equivalent altitude of 10,000 feet and significant hypoxia is prevented. However, decompression sickness which tends to occur at altitudes above 30,000 feet as a function of individual susceptibility, time of exposure, exercise, and terminal altitude, may complicate prolonged suit flights unless adequate preflight denitrogenation has been accomplished. The CSU-4/P has demonstrated its effectiveness by protecting airmen at simulated altitudes of 100,000 feet and above for 2 hours or longer. During rapid decompression, the suit responds with little or no lag time to protect the wearer. In this respect, the "quick don" garment does not differ remarkably from the other partial pressure suits described above.

FULL PRESSURE SUITS

At the present time, full pressure suits of the A/P22S-2 and A/P22S-3 types are used in certain high performance aircraft. Full pressure suits have also been incorporated in the life support systems of the Air Force/National Aeronautics and Space Administration X-15 aircraft and the NASA Mercury, Gemini, and Apollo spacecraft.

The full pressure suit consists of these basic components: helmet, torso, gloves, and boots. The helmet is similar to that used with the bladder suit except that it contains a face seal which separates the helmet and suit cavities. The torso includes an inner layer made of neoprene-impregnated fabric cloth which serves as a gas container and, in conjunction with an outer restraining layer, prevents overinflation and preserves external suit configuration. Special restraining straps and breakpoints provide mobility when inflated. A series of pressure-sealing zippers facilitate donning. The gloves, which must be tight, connect to the torso sleeves in the wrist areas. These gloves are donned last and removed first. Proper glove fit is important if finger mobility and touch sensitivity are to be maintained. With the helmet, torso, and gloves in place, the suit is a completely airtight system. The boots, which are worn over the inclosed feet, provide protection to the suit during walking.

The full pressure suit, as part of the aircraft life support system, requires a source of breathing oxygen, a source of gas (such as compressed air, nitrogen, or oxygen) for suit pressurization, and an aneroid controller which senses cabin pressure and controls suit gas flow accordingly. A seat kit, that houses an emergency oxygen supply for use during bailout, completes the system. Highly reliable regulators of small size have been developed to supply 100% breathing oxygen to the helmet faceplate area at all times from the ground up. The aircraft also delivers a flow of cool dry air through the suit, a necessity to prevent hyperthermia. Should cabin pressurization fail while the aircraft is at an extreme altitude, the aneroid controller senses the change in cabin pressure and immediately activates a suitable flow of 100% breathing oxygen to the helmet and necessary gas pressure for inflating the suit torso and gloves. Regardless of the final cabin pressure, the internal suit altitude (body altitude) does not exceed 35,000 (179 mm Hg) feet.

The suit is compatible with the aircraft emergency escape system. In the event of ejection at high altitude, the backup oxygen supply carried in the seat kit will automatically pressurize the suit and deliver breathing oxygen as necessary during the free-fall period. The garment is designed to withstand the windblast associated with high-speed escape and will also protect against frostbite during exposure to subzero stratospheric temperatures. In addition to protecting aircrewmen at altitude, the full pressure suit provides a reasonable degree of protection against exposure to wet cold. This is particularly important in winter operations at the higher latitudes where water temperatures of 28 to 30° F can incapacitate an unprotected downed flier in minutes.

GENERAL CONSIDERATIONS

Even though current pressure suits provide reliable protection at altitude, improvements in comfort and freedom of motion are desirable. Ideally, a suit should not restrict motion or visibility in routine flight, during an in-flight emergency or during an emergency escape procedure. In addition to providing altitude protection, a suit must resist windblast during bailout and act as a survival garment against both wet cold and dry cold conditions. The Flight Surgeon, who is aware of the difficulties of integrating an all-purpose pressure suit system with the flier and the aircraft, is often able to make useful suggestions and benefit the mission.

Compared to present garments, the early pressure suits provided marginal protection and often added unique stresses of their own. As a result, it was necessary to carefully screen candidates for pressure suit training with particular reference to cardio-respiratory fitness. In the past few years, however, suit technology has improved remarkably and present Air Force garments exert few, if any, measurable physiological penalties. Therefore, an aircrewman who is medically qualified for Flying Class II and has also participated in a low-pressure chamber flight, as conducted by the physiological training program, should be acceptable for suit training.

REFERENCES

The reader should insure the currency of listed references.

AFM 64-4, *Handbook of Personal Equipment.*

AFP 161-16, *Physiology of Flight.*

Bancroft, R. W., Medical Aspects of Pressurized Equipment, Chapter 13, *Aerospace Medicine,* H. G. Armstrong, Baltimore, Williams & Wilkins (1961).

Hall, A. L., and Martin, R. J., *Prolonged Exposure to the Navy Full Pressure Suit at Space Equivalent Altitudes,* Aerospace Medicine, 31:116-122, February 1960.

Henry, J. P., Drury, D. R., Greeley, P. O., and Bennett, V. R., *A Study of the Physiological Requirements of an Emergency Pressure Suit Permitting Survival at 60,000 Feet,* Memorandum Report No. TSEAA-660-100, 5 May 1946.

Lutz, C. C., *Development of an Emergency Pressure Suit (Coveralls, High Altitude, Type CSU-4/P),* Wright Air Development Center (WADC) Technical Note 59-148, July 1959.

McGuire, T. F. and Leary, F. J., *Physiology and Operational Comparison of Current Partial Pressure Suits (II),* WADC TR-57-536, August 1957.

McGuire, T. F., *Physiology and Operational Comparison of MC-1 and MC-3 (MC-4) Partial Pressure Suits,* WADC TR-57-536 (I), October 1960.

Pinc, B. W., *MC-3, MC-4 Altitude Suit Assemblies, Description, Fitting and Maintenance,* WADC TR-56-654, December 1956.

Randel, H. W., Taylor, I. T., and Burnett, L. S., *Further Studies of Medical Aspects of Partial Pressure Suit Indoctrination,* Journal of Aviation Medicine 28:134-141, April 1957.

Technical Manual; Operation, Service and Repair Instructions: *High Altitude Gloves, Type MG-1,* TO 14P3-3-11.

Technical Manual; Operation, Service and Repair Instructions: *High Altitude Helmet, Type MA-2,* TO 14P3-4-21.

Technical Manual; Operation, Service and Repair Instructions: *High Altitude Helmet, Type HGU-8/P,* TO 14P3-4-61.

Technical Manual; Operation, Service and Repair Instructions: *Partial Pressure, High Altitude Suits, Types MC-3, -3A, -4, -4A,* TO 14P3-6-51.

Technical Manual; Operation, Service and Repair Instructions: *Outfit Flying, Full Pressure, High Altitude, Type A/P22S-2,* TO 14P3-6-81.

Technical Manual; Operation, Service and Repair Instructions: *Coveralls, High Altitude, Type CSU-4/P,* TO 14P3-6-91.

Technical Manual; Fitting, Donning, Operation and Maintenance Instructions: *High Altitude Full Pressure Flying Outfit, Type A/P22S-3,* TO 14P3-6-101.

Wilson, C. L. and Zinn, M. J., *Medical Problems in Testing High Altitude Pressure Suits,* Aerospace Medicine 31:49-56, January 1960.

Wilson, C. L., *Operational Use of the USAF Partial Pressure Suit,* Aerospace Medicine 32:691, 1961.

Wilson, C. L., *Physiological Protection of the CSU-4/P High-Altitude Pressure Suit,* Technical Documentary Report No. AMRL-TDR-62-112, Aerospace Medical Division, Wright-Patterson AFB, Ohio, September 1962.

Wilson, C. L., *Wiley Post: First Tests of High Altitude Pressure Suits in the United States,* Aerospace Medicine 34, October 1962.

Chapter 19

WORLDWIDE AEROMEDICAL EVACUATION

OPERATIONAL CONCEPTS

Department of Defense policy requires the use of air transportation for the evacuation of the sick and wounded, unless medically contraindicated, when appropriate aircraft can be made available. The Department of the Air Force implements this policy by establishing and operating aeromedical evacuation systems for peacetime and limited war requirements. By integrating Air Force Reserve and Air National Guard units, the systems can be quickly expanded to meet full wartime requirements.

At the present time, the Air Force operates aeromedical evacuation systems to meet the following requirements: a. Between medical facilities within the Continental United States (CONUS); b. within oversea areas where US Armed Forces are stationed; and c. from oversea areas to the CONUS. Thus, all US Forces, wherever located, are provided with aeromedical evacuation support.

Several aeromedical evacuation systems are in operation at this time and are identified according to geographical/operational factors as *domestic, intertheater,* and *intratheater*. A domestic system operates within the CONUS; two intratheater systems operate within oversea areas. A tactical system is capable of being put into operation by units of the Tactical Air Command. Sometimes, the terminology "tactical aeromedical evacuation system" is used; it refers to the intratheater systems. Similarly, the term "strategic" refers to the evacuation of patients between oversea areas.

The intertheater systems are the least complex. The flow of patients is in one direction from a limited number of oversea aerial ports to one of several in the United States. By contrast, the domestic and intratheater systems operate into large numbers of airfields, perform many special missions, and provide a 24-hour, on-call emergency service. All systems perform essentially the same functions and require the coordinated efforts of similar activities.

Several kinds of air transport and medical service activities combine or coordinate their efforts to make an aeromedical evacuation system operationally effective. A listing would include at least the following: (1) Air transport activities, such as transport and troop carrier units, airlift command posts, and air and ground communications; (2) air terminal and aerial port activities, such as air evacuation control centers, flight line services, food services, and ground transportation; and (3) medical activities, such as casualty staging, medical regulating agencies, originating, en route and destination hospitals, and aeromedical evacuation units. The actions of all these elements must be closely coordinated. Poor coordination will result in loss of airlift and a breakdown in the orderly flow and timely evacuation of patients to medical treatment facilities.

Continental US Operations—The Domestic System

The mission in the CONUS is to operate a domestic aeromedical evacuation system for the transfer of patients from aerial ports of debarkation to destination hospitals, and between medical facilities within the United States. The operation of this system presently involves aeromedical airlift squadrons, detachments, casualty staging units, aerial ports, aeromedical evacuation control centers, about 500 airfields, and approximately 200 military and 185 Veterans' Administration and Public Health Service hospitals.

The peacetime mission is accomplished with pressurized aircraft that are used exclusively for transporting patients. The domestic system operates a. A scheduled coast-to-coast trunkline service to keep aerial ports cleared, to provide a connection with feeder flights at terminals along the route, and to transfer patients between terminals on the trunkline; b. feeder flights to transfer patients between trunkline terminals and hospitals not on the trunkline; c. a scheduled service to Alaska, Northeast Caribbean, and adjacent Atlantic areas; and d. semischeduled and special flights to transfer patients between medical facilities that are not serviced by the trunkline. This MAC system provides a network of daily flights, which could be quickly augmented with Air National Guard and Air Force Reserve units for wartime operations (see figure 19–1).

Overseas to CONUS Operations—The Intertheater Systems

The mission of an intertheater system is to provide aeromedical evacuation from oversea areas to the CONUS. Two intertheater systems may be identified with the following geographical areas of responsibility: a. From the Far East-Pacific area and b. from the European area. These systems are an integral part of the MAC global air transport system which provides logistical air support for all US Forces outside the CONUS.

The delivery of cargo, personnel, and mail to these oversea locations creates a large return airlift capability, part of which is used for the evacuation of patients. The utilization of return airlift as the sole resource for aeromedical evacuation from oversea areas is one of the operational distinctions of intertheater systems which would also be employed by the other systems in the time of war.

The efficient operation of intertheater systems requires (1) multiengined, pressurized transport aircraft equipped with removable airline seats and litter support devices for quick conversion from passenger/cargo to aeromedical configuration; (2) casualty staging facilities at aerial ports of embarkation and debarkation; (3) sufficient numbers of aeromedical flight crews and equipment located at aerial ports and intermediate terminals; and (4) appropriately located aeromedical evacuation control and liaison centers staffed by medical service personnel who are familiar with aeromedical evacuation procedures and air transport operations.

Modern fleets of pressurized, dual-purpose jet aircraft are used for peacetime intertheater operations, consisting of C–141 aircraft, at this time. For critical wartime situations, the C–130 turboprop cargo transports would be available also.

During peacetime, the heavy cargo/passenger transport aircraft is capable of carrying a mixed litter/ambulatory load of approximately 70 patients. The basic medical crew consists of two flight nurses and three aeromedical evacuation technicians. In wartime, the number of patients carried would be greater, probably approximating the maximum capacities of the various aircraft. Aeromedical crews would be augmented, when required; however, during the initial period of a national emergency, the nonavailability of medical crews could result in some flights having less than a basic crew aboard.

Intratheater Systems

The mission of an intratheater system is to provide aeromedical evacuation for all US Forces within a theater of operations or oversea area. The Air Force presently operates two intratheater systems. One encompasses the European-Mediterranean-Near East area (figure 19–2); the other, the Far East-Pacific-Southeast Asia area (figure 19–3). For the peacetime mission, these systems operate in a similar manner and provide services comparable to the domestic system. Under wartime conditions, support of combat operations is the primary task, requiring the use of troop carrier and assault aircraft, involving a change in operational procedures from the single mission to the dual mission or "return airlift" concept.

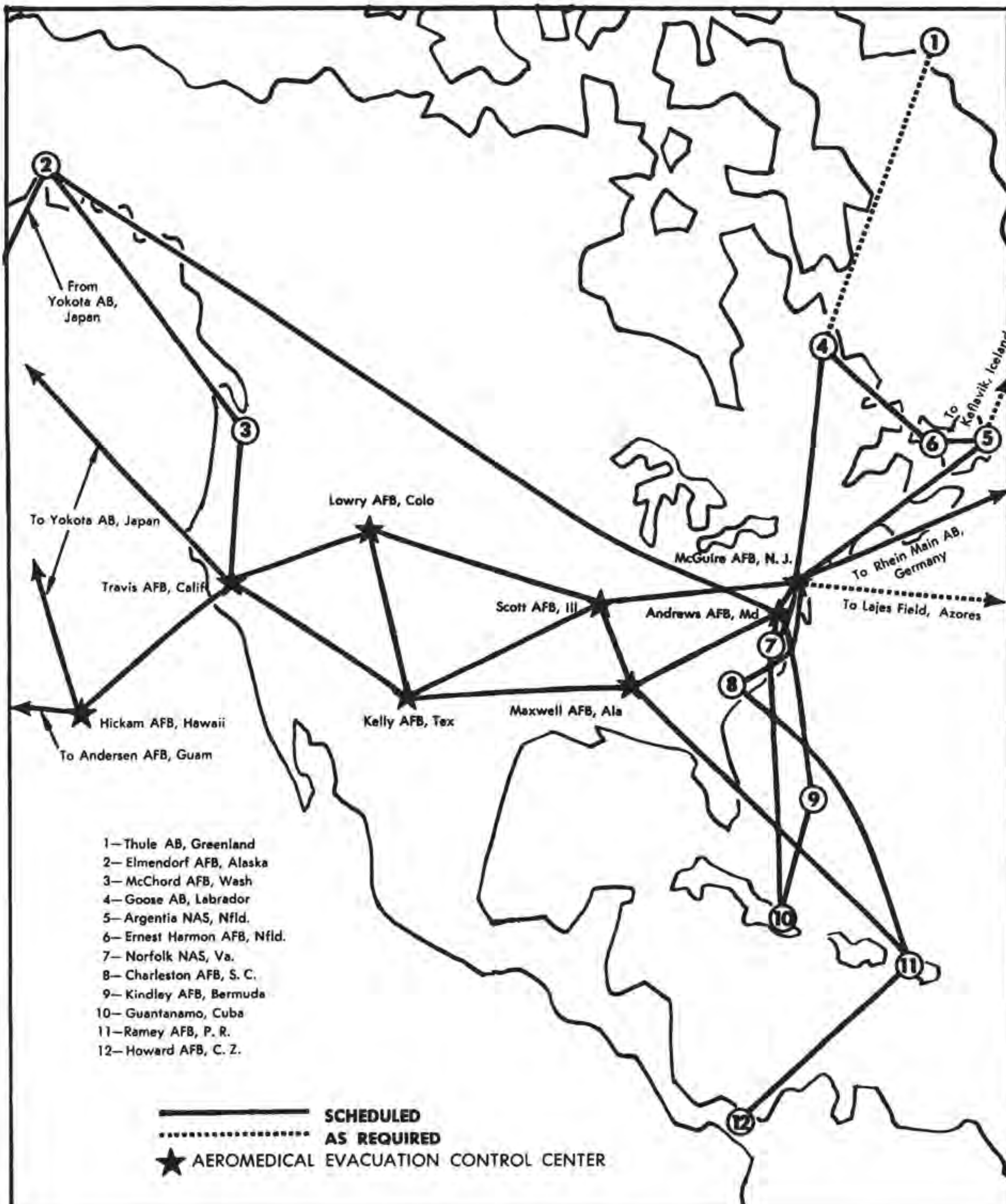


Figure 19-1. Domestic System.

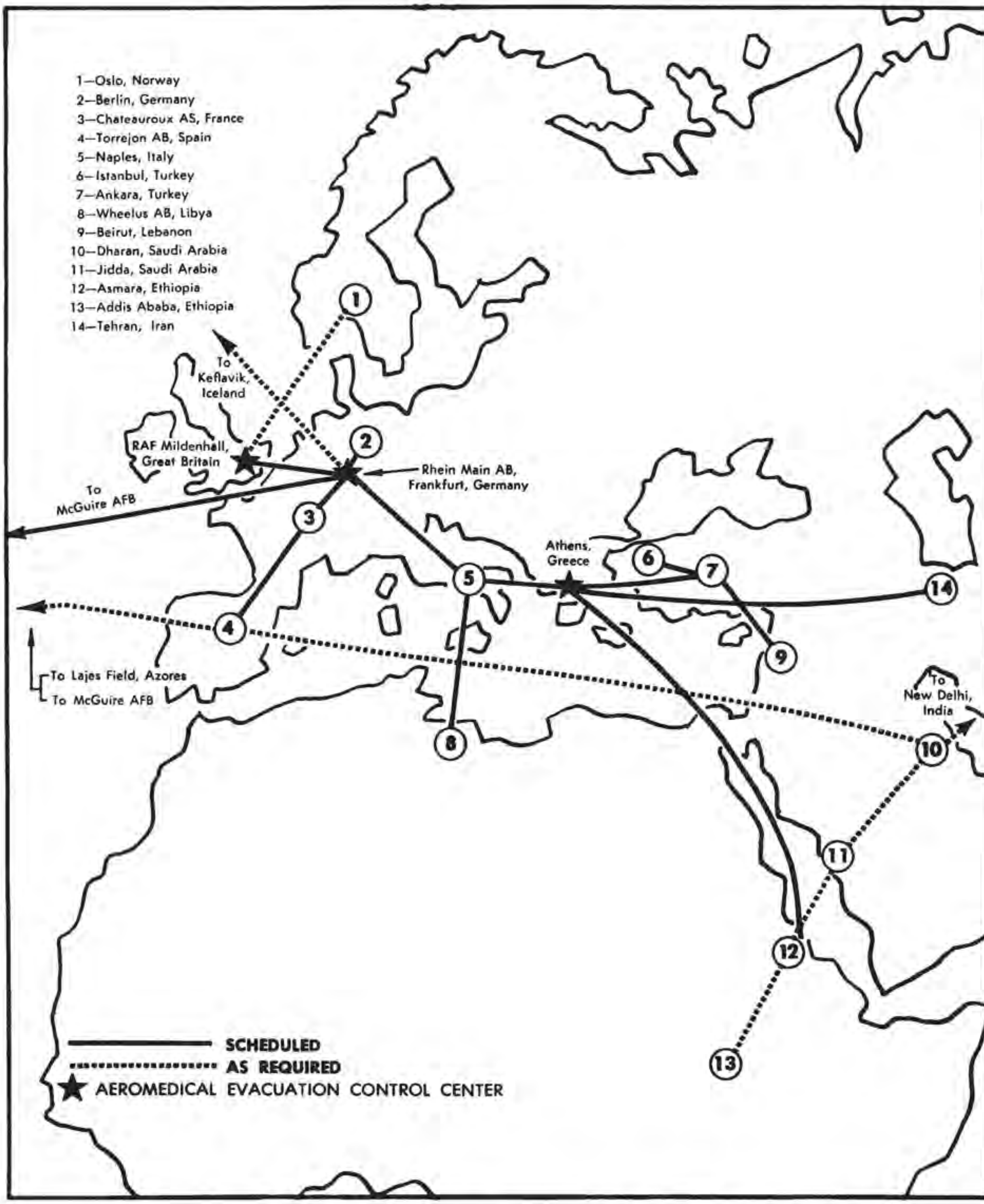


Figure 19-2. European-Mediterranean-Near East Area.

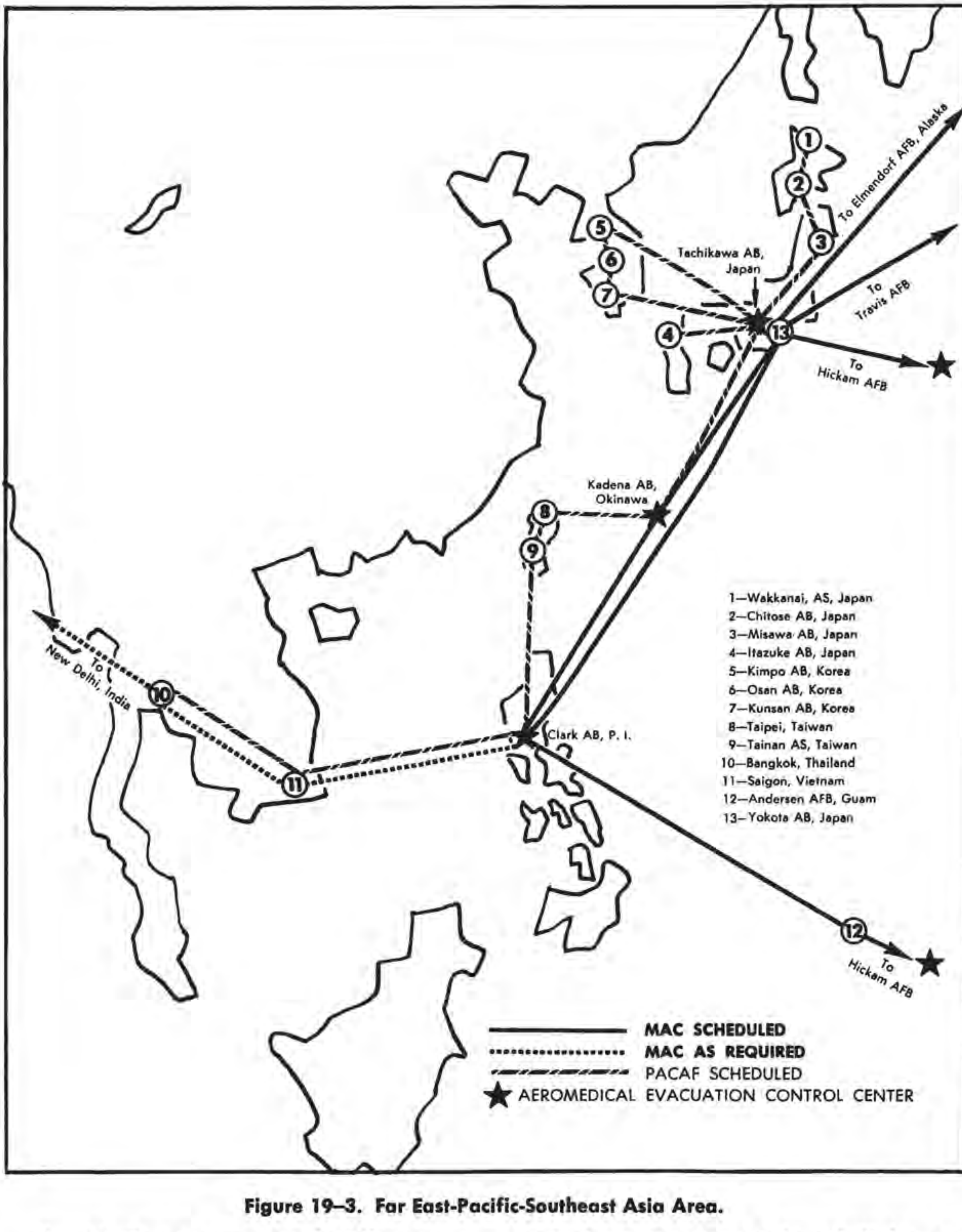


Figure 19–3. Far East-Pacific-Southeast Asia Area.

The Air Force recognizes that the peacetime mission of intratheater systems includes the evacuation of women and children, and involves medical and surgical conditions which would not normally be encountered in wartime. Pressurized aircraft with comfortable accommodations are used when possible, and both outbound and inbound flights are normally flown for the aeromedical mission, using the outbound flight to return recovered patients to their home stations. Passengers normally use seats not required for patients.

Intratheater aeromedical evacuation, being a collateral function of logistical air support operations, has the entire theater airlift resources at its disposal. This airlift, consisting primarily of cargo/troop carrier aircraft, will form the backbone of wartime evacuation resources. Therefore, it is important that troop carrier and aeromedical evacuation elements train and exercise in dual-mission operations through periodic command exercises and operational readiness tests, and also participate in joint field exercises when possible.

Intratheater systems are organized, staffed, equipped and oriented to the primary mission—combat support. The realities of peacetime deployment of forces are recognized, however, and every effort is made to maintain intratheater systems which provide a service appropriate to peacetime conditions while maintaining responsiveness to the wartime mission.

All of the normal requirements for casualty staging, coordination, control and liaison, aeromedical flight crews, special equipment, and standard operating procedures also apply to intratheater operations. Additional requirements include the ability to: a. Support air-landed airborne operations, b. rapidly convert to litter configuration and load all types of assault, cargo, and troop carrier aircraft, and c. integrate with the wartime logistical air support system without any significant changes in command, organization, deployment or operating procedures.

Aeromedical Evacuation Coordination, Control, and Communication

The advantages of aeromedical evacuation, when compared with other modes of transportation, may be measured in terms of lives, time, and resources saved. A constant effort is made, therefore, to reduce the time between the entry of patients into the evacuation system and their delivery at destination hospitals. Two related actions—efficient use of aircraft and short turn-around or ground time—contribute directly to this objective. The degree of success in achieving this objective is largely dependent upon the effectiveness of coordination and control.

Coordination, which is effected by all elements of the system and by activities using the system, keeps all appropriate agencies and activities informed of evacuation requirements, estimated aircraft arrival times, changes in requirements and estimated times of arrival (ETAs), and any other details which should be made known to other activities.

Aeromedical airlift control and patient traffic control are performed by elements of the evacuation system that are located at aerial ports and air terminals. Aeromedical airlift control assures that the scheduling and routing of aircraft will satisfy the evacuation requirements within the area of operations. Patient traffic control insures that the number of patients by type, delivered to specific airfields within the area of responsibility, does not exceed the space available at the specific points of pickup. These control functions are performed by aeromedical evacuation units at key terminals and aerial ports.

Effective coordination and control require the use of all available means of communication. All aeromedical evacuation elements must have authority to use whichever means are appropriate to the situation. The more widespread the area of responsibility, the greater are the problems of communication and the greater the importance of timely communication.

The medical and logistical advantages of aeromedical evacuation are quickly lost without effective day-to-day coordination and control, as were practiced in certain instances during World War II, the Korean War, and the Vietnam Conflict.

Casualty Staging

Present operations are based on the concept that aeromedical evacuation is a collateral function of airlift operations, and that the coordination and control procedures for the employment of airlift are essentially the same for both. The most effective coordination and control are achieved when casualty staging activities are employed at key points in the system.

Casualty staging, the counterpart of aerial port squadrons which control and supervise the delivery and loading of troops and cargo, provides similar services for patients at aerial ports and terminals. Casualty staging increases aircraft utilization and decreases aircraft turn-around time. The in-transit time of patients is shortened, airlift is not lost, nor are aircraft departures delayed because of late arrival of patients. Furthermore, patients are not held in ambulances on the flight line because of late arrival of aircraft, and advantage can also be taken of opportune airlift. In effect, all of the details of coordination, communication, and patient handling and care at the airfield are simplified and more efficiently managed in the time available through the use of casualty staging.

A listing of casualty staging functions includes coordinating aeromedical evacuation matters within the area of responsibility and regulating the flow of patients. Included among the required additional duties are providing or arranging for shelter; medical care; feeding; medical screening; administrative processing; ground transportation and loading of patients; and otherwise providing for the welfare and expediting the transfer of patients entering, en route, or leaving the aeromedical evacuation system.

AEROMEDICAL AIRCRAFT

The purpose of this section is to discuss the various aircraft used in aeromedical evacuation. Table 19-1 compares the various types of aircraft and is an index for the narrative descriptions of the aircraft that follow it.

The figures given in this chart may vary in different models of the same type aircraft. The approximate cruising speeds will vary with load and distance to be flown. The ambulatory and litter loads will vary with different models and are governed by the regulations of the operating organization. Equipment also varies with individual aircraft of the same type.

C-131 Consolidated-Vultee "Convair"

The C-131, "The Samaritan" (figure 19-4), is a twin-engine aircraft especially designed for aeromedical evacuation. Its pressurized cabin can accommodate a maximum of 27 litter patients or 32 ambulatory patients. A combined load uses 12 litters along the left side and 17 rearward-facing airline seats on the right side.

This aircraft is equipped with standard litter-securing devices. The litters can be placed in three tiers of four each on both sides, with one tier of three on the rear left side opposite the latrines. Normally, however, this last tier space is used for baggage and equipment stowage.

Litter patients are loaded through the cargo door in the left rear section. These patients are placed in the tiers, feet forward. Ambulatory patients can be loaded by way of the built-in steps in the right forward section of the aircraft.

Special features include special lighting facilities, a well-equipped galley, individual fresh-air blowers, loudspeaker system, permanently partitioned latrines, and adequate sound attenuation.

The C-131 is the primary peacetime aeromedical aircraft. It is one of several aircraft used in the MAC domestic and intratheater systems.

C-118 Douglas "Liftmaster"

The C-118 (figure 19-5) is a four-engine aircraft with a pressurized cabin. It has a capacity of 60 litter patients or 61 ambulatory patients. It is equipped with standard litter support straps and wall brackets. There are individual oxygen supply controls and 24-volt electric outlets.

Patients are loaded through the rear main cargo doors. For ground operation in aeromedical work, external air-conditioning and heating are required. This aircraft is automatically pressurized and air-conditioned in flight.

C-141 Lockheed "Starlifter"

In 1965, the Lockheed C-141 "Starlifter" succeeded the Boeing C-135 as the major MAC long-range jet transport. The C-141 (figures 19-6 and 19-7) is a high speed, long-range, high swept-back wing monoplane, powered by four turbofan engines. Being

Type	No. of Engines	Cruise	Maximum Ambulatory Patients	Maximum Litter Patients	Name	Civilian Designation
Military Airlift Command						
Prop						
C-131	2	240	32	27	Samaritan	Convair 240
C-118	4	230	61	60	Liftmaster	DC-6
Jet						
C-141	4	425	95	72	Starlifter	L-300
Air National Guard						
Prop						
C-97	4	235	73	54	Stratocruiser	
C-121	4	240	71	44	Super Constellation	
Other Aircraft with Aeromedical Capability						
C-47	2	145	27	24	Skytrain	DC-3
C-54	4	171	49	36	Skymaster	DC-4
C-7	2	134	30	20	Caribou	
Turboprop						
C-130E	4	280	85	70	Hercules	
Helicopter						
HH-43	1	80	8	6		
H-19	1	90	10	6		
Aeromedical Aircraft to Replace C-131 and C-118						
Jet						
C-9A	2	480	46	40		DC-9

Figures for patient loads with full aeromedical crews are for maximum ambulatory and litter patient loads.

Figure for conversion of seats to litters (seat equivalents):
a. 2 seat side aircraft = 3 or 4 litters replaces 6 seats.
b. 3 seat side aircraft = 3 or 4 litters replaces 9 seats.

TABLE 19-1. AIRCRAFT USED IN AEROMEDICAL EVACUATION.

145 feet long with a wing span of 160 feet, its spacious cargo compartment can be equipped to carry over 150 troops and up to 80 litters in rows of three and four tiers each. In this latter configuration, there is space for up to sixteen attendants. Various combinations of litters and seats for ambulatory patients are possible. The usual configuration is 27 litters and 42 seats. Average cruising speed is 425 knots at an average cruising altitude of 33,000 feet. With a litter load of 80, the nonstop range is 5,000 nautical miles. Time taken to convert from cargo to patient use is less than two hours.

It must be emphasized that the C-141 is a multimission aircraft, capable of transporting troops or over 50,000 lbs of cargo outbound and returning on aeromedical evacuation missions.

Crew and patients have separate oxygen systems. The latter system can supply 80 litter patients with a continuous flow of oxygen for nine hours at 25,000 feet cabin altitude. The oxygen flow can be manually initiated or occurs automatically at cabin altitudes of 12,500 feet. Some of the oxygen distribution lines are permanently installed and others can be attached with the litter stanchions. Two regulator panels are available for the therapeutic oxygen system. Masks are the plastic throw-away type with quick connect-disconnect fittings.

Two identical and parallel air-conditioning systems control the environment of the aircraft, supplying conditioned air. Temperature control is achieved through ceiling and floor heating. Cabin temperatures are comfortable. In-flight relative humidity varies from 3% to 25%, a distinctively suboptimal level and one which is given special consideration when tracheostomized patients are carried. Interior noise levels, though high by airline criteria, conform to military standards.

The aircraft is designed to operate with an 8.2 psi normal cabin pressure differential, with 8.6 the maximum. This allows the pressurization system to maintain sea level cabin pressure until the aircraft reaches 21,000 feet. At 33,000 feet, the usual cruising alti-

Figure 19–4. C–131 Consolidated-Vultee "Convair."

Figure 19–5. C–118 Douglas "Liftmaster."

Figure 19–6. C–141 Lockheed "Starlifter."

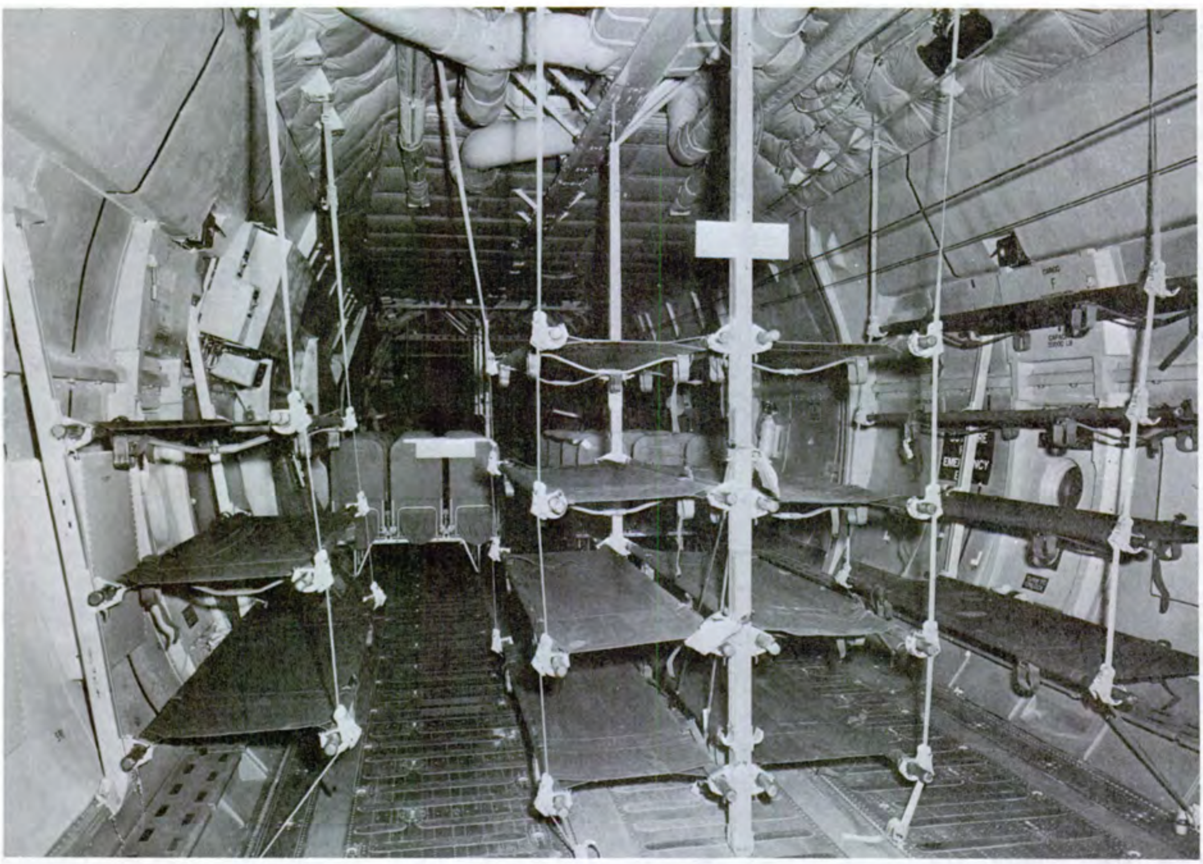


Figure 19–7. Interior View of C–141.

tude, a cabin altitude of 5,500 or less, is maintained. If required, sea level altitude may be achieved even at a flight level of 31,000 feet. At a level of 40,000 feet, the cabin altitude of 8,000 feet or less is possible. No instance of loss of cabin pressurization in an aeromedical evacuation flight has been reported in the C–141, and only one instance is known in its C–135 predecessor. The rate of cabin pressure change can be controlled for both ascent and descent.

A palletized comfort station is located at the forward end of the cargo compartment. The unit contains two flush-type latrines, wash basins, and well-equipped galley facilities. The necessary electrical and waste removal provisions for the comfort pallet are permanently installed.

Even the baggage storage is palletized. Five to six 20-man life rafts are carried and each patient has available an individual specially designed life vest.

C–97 "Stratocruiser"

The C–97 "Stratocruiser" (figure 19–8) is a midwing, heavy transport aircraft, powered by four radial piston engines. When seen head-on, the double-decked fuselage resembles a figure 8. Integral ramps have been incorporated for easy loading of patients. Standard webb strapping and wall brackets are used to secure litters. A maximum of 73 ambulatory or 54 litter patients can be accommodated.

C–97s are being used in the Air National Guard System.

C–47 Douglas "Skytrain"

The C–47 "Skytrain" (figure 19–10) is a piston-powered, twin-engine, nonpressurized aircraft. It has a litter capacity of 24 or a seating capacity of 27. There are six tiers with four litters in each tier. Standard litter support straps and wall brackets are used to secure the litters. Bucket-type seats or Evans canvas seats are used for ambulatory patients.

The C–47 is a low-door aircraft; therefore, no loading device is required in the onloading or offloading of patients.

The position of the litter patients in this aircraft is head forward, due to the plane's tail-low position on the ground.

The C–47 is not used for MAC aeromedical evacuation.

C–121 Lockheed "Constellation"

The C–121 Super "Connie" (figure 19–9) is a single-deck, four-engine (piston) aircraft with a pressurized cabin. This aircraft can carry 71 ambulatory or 44 litter patients. Standard webb strapping and wall brackets are used to secure the litters.

Ramps or mechanical loading devices are required when loading litter patients.

C–121s are being used in the Air National Guard System.

C–54 Douglas "Skymaster"

The C–54 "Skymaster" (figure 19–11) has four piston engines and a single deck, and is nonpressurized. The number of litter spaces ranges from 20 to 36. The maximum litter capacity is 32 in eight tiers of four litters each, plus eleven passenger seats. It has individual oxygen supply controls, built-in ventilation, and solar-reflecting paint. All C–54's are high-door aircraft requiring a special ramp or loading device for loading. The position of the litter patients in this aircraft is feet forward. The C–54 is not used in the MAC aeromedical system.

C–7 Caribou

Formerly a US Army theater cargo aircraft designated CV–2B, aircraft is used in theater of operations as a cargo/utility/evacuation aircraft.

The Caribou is a fixed-wing aircraft having a range of more than 1,100 nautical miles at a cruising speed of 134 knots. It has a crew of two and a maximum passenger capacity of 30. It can be used to carry up to 20 litter patients.

The Caribou is a rear-loading aircraft primarily designed for moderately heavy combat cargo support (see figures 19–12 and 19–13).

C–130E Lockheed "Hercules"

The Lockheed C–130E "Hercules" (figure 19–14) is a long-range transport plane with a pressurized cabin. It is capable of accommodating 85 ambulatory patients or 70 litter patients with attendants. The litters are carried aboard the airplane through the cargo-loading ramp door and are installed in four lengthwise rows in the cargo compartment. Stowage provisions for the litter-support stanchions are provided in the cargo compartment forward bulkhead.

The C–130E can land and take-off on short runways and can be used on landing strips

Figure 19–8. C–97 "Stratocruiser."

Figure 19–9. C–121 Lockheed "Constellation."

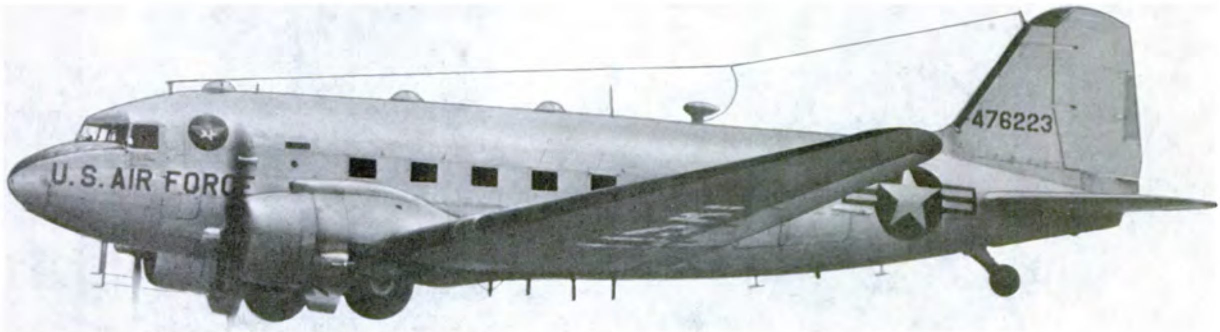


Figure 19–10. C–47 Douglas "Skytrain."

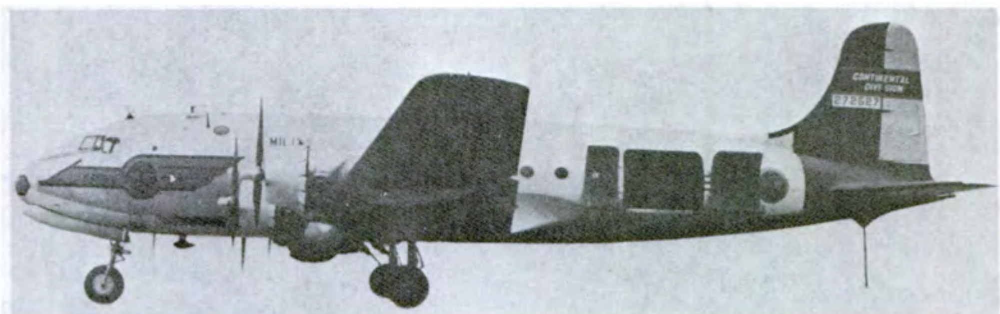


Figure 19–11. C–54 Douglas "Skymaster."

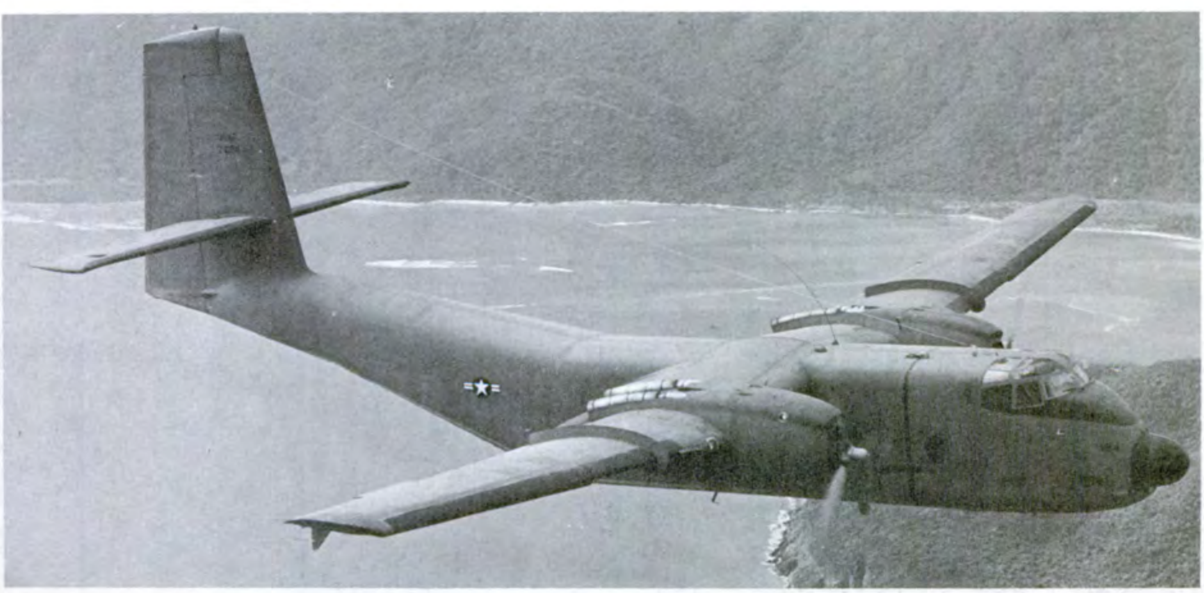


Figure 19–12. C–7 Caribou.

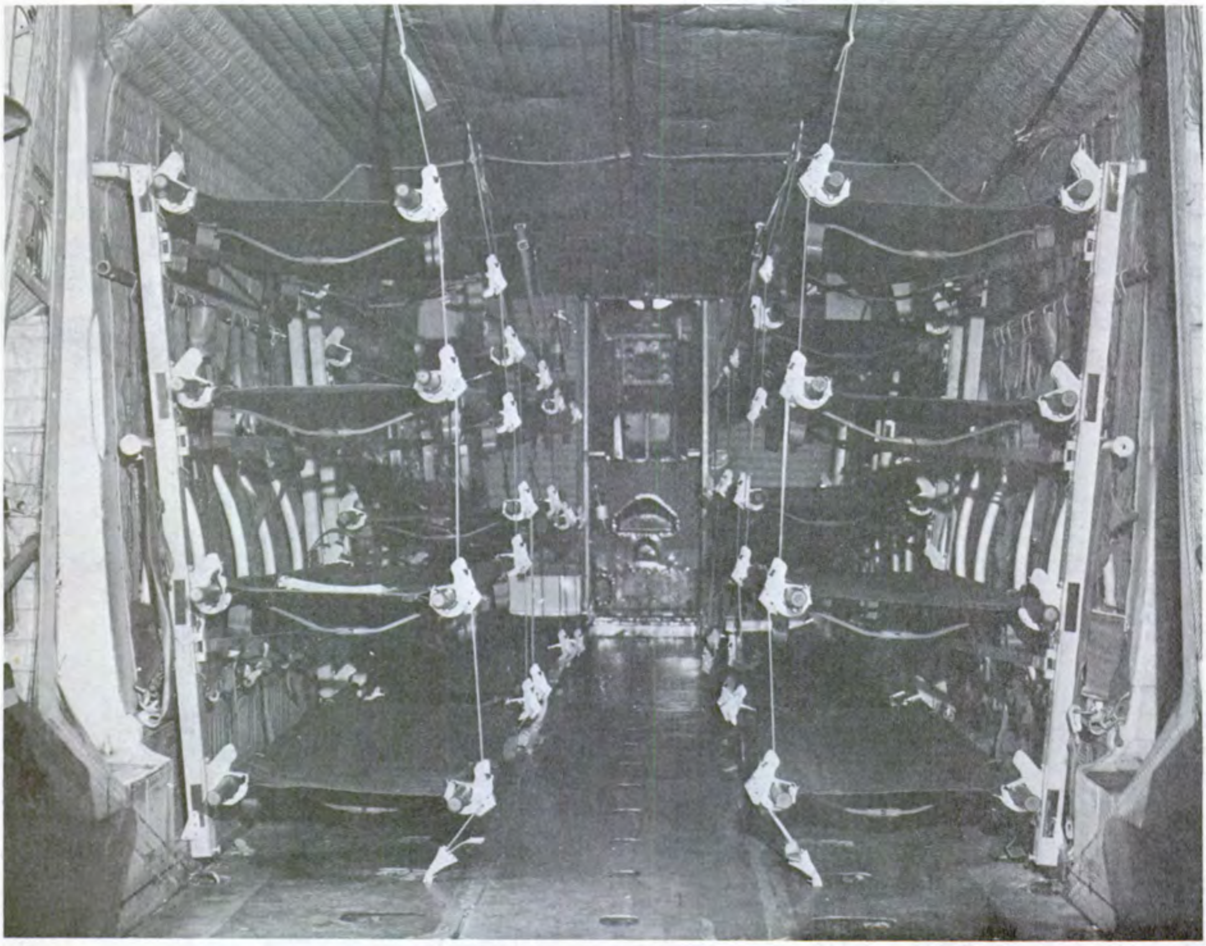


Figure 19–13. Interior View of C–7.

Figure 19–14. C–130E Lockheed "Hercules."

Figure 19–15. HH–43.

Figure 19–16. H–19 "Sikorsky" Helicopter.

such as those usually found in advance base operations. It can also carry heavy loads long distances without refueling. Power for this airplane is supplied by four turboprop, constant-speed engines.

Normal use is within a theater of operations.

The HH–43 (figure 19–15) is used primarily for firefighting in crash rescue. It normally carries a pilot and rescue crew of

HH-43

three, and can be configured to accommodate eight ambulatory or six litter patients.

H-19 "Sikorsky" Helicopter

The H-19 (figure 19-16) is a single-engine, single-rotor, three-blade helicopter that can accommodate six litter patients or eight to 10 ambulatory patients, depending upon their weight. Two tiers of three litters each are secured with standard webb support straps and wall brackets. Patients may be easily lifted directly into the aircraft.

C-9A

A significant milestone in the evacuation of sick and injured occurred when the C-9A was selected as the medium-sized jet aircraft for the domestic aeromedical evacuation mission. This intermediate range aircraft, the first specifically designed for the purpose of aeromedical evacuation, has the capacity of carrying 46 ambulatory or 40 litter patients, or various combinations.

The C-9A incorporates many features for providing greater comfort to patients and faster transfer from aerial ports to military hospitals close to the patients' homes. Configuration includes a special selfcontained, power-operated loading ramp and airstairs, an integral oxygen system to supply both emergency and therapeutic oxygen, a special patient-care area similar to hospital intensive-care units, flight nurse's station, two galleys, and storage areas for equipment, supplies and waste.

This aircraft contributes significantly to modernization efforts for the best possible service to our military personnel and their dependents.

CARE AND TREATMENT OF PATIENTS DURING FLIGHT

Experience has shown that almost every patient who can be evacuated by any available means can be evacuated by air, provided: the opportunity exists, the aircraft is suitably equipped with facilities, and the medical personnel aboard have a knowledge of the physiological changes of patients in flight. These changes are simple to understand. In cases where flight factors may involve either hardship or definite risk to the patient, physiological change can be minimized during flight if pressurized-cabin aircraft are used.

The principal changes in flight which may produce dangerous physiopathological states in the patient are: a. Decrease in the partial pressure of oxygen; and b. expansion of air or gas trapped in any body cavity.

Certain types of patients will require additional oxygen even at altitudes under 10,000 feet, due to hypoxia caused by disease or injury. Pulmonary edema or pneumonia may impede passage of oxygen to the blood. In the case of anemia or malaria, the transportation of oxygen may be inadequate. The entire column of blood may move too slowly to carry oxygen in sufficient quantity to the tissues, as in circulatory collapse caused by shock or cardiac failure. The tissues themselves may be so damaged that they are unable to use the oxygen, as in certain types of poisoning. Finally, thoracic injury may reduce ventilatory capability. Any one of these factors, added to the decrease in oxygen pressure on ascent, makes it necessary to supply supplementary oxygen from the time of takeoff.

Air or any gas trapped in the body cavities expands in direct proportion to the decrease in pressure. This increased volume becomes significant at 18,000 feet where the volume of air or gas in the body is doubled. Quite apart from intense discomfort and actual pain caused by certain types of injury, this expansion of gas at high altitude may constitute a real danger, as in the probability of rupturing a recently sutured intestine, and by the disturbance of cardiopulmonary dynamics in cases of pneumothorax.

AFR 164-1 presents very broad guidance with respect to the selection and screening of patients for aeromedical evacuation. This regulation also indicates the broad categories of cases that will require special consideration during evacuation. The specific nature of some of these considerations is presented in the following paragraphs.

Effects of Decreased Pressure

Gastrointestinal Tract Disturbances:

There are four principal factors associated with the production of abdominal symptoms on ascent to altitude. These are: a. The quantity of gas in the bowel, b. the cabin altitude attained which determines the amount of gas expansion, c. the ability of the bowel to eliminate the expanding gas, and d. the sensitivity of the bowel to pain.

In regard to quantity, most of the gas found in the gastrointestinal tract is believed to be swallowed air which is ingested with, or independent of, foods and fluids. Other sources of gas are the action of bacteria on food residues and gas diffusion from the blood stream. Patients who show apprehension and anxiety can quickly fill the stomach and colon with gas and experience a bloated feeling even at sea level. The chewing of gum before ascent to altitude should be restricted because, even though chewing gum helps to attain an equalization of gas pressures on the ear drum, large quantities of air may be swallowed with the saliva. An increased amount of gas in the bowel may also be associated with the ingestion of high carbohydrate diets, melons, and carbonated water.

It is quite possible that the site of a gas pocket in the gastrointestinal tract may be an important consideration in determining the degree of abdominal pain associated with ascent to altitude, since expansion of gas in the ileum has been shown to be attended by severe symptoms. It is also well known that distention of the duodenum results in a marked tendency to nausea and vomiting, which may be accompanied by a vasomotor phenomenon, such as a feeling of chill and cold sweat.

In theory, the expansion of gas at even a moderate altitude may be sufficient to cause rupture of a diseased viscus, especially in such cases as ulceration and weakening of the walls, as in peptic, typhoidal, amebic, and tuberculous ulcers located in various portions of the gastrointestinal tract. Some of these ulcerations are deep enough to leave the walls extremely thin, and, therefore, are subject to spontaneous perforation at ground level. Conceivably, gas expansion at altitude could, in borderline cases, exert enough pressure to break a thin wall. The ensuing dangers from chemical shock and peritonitis are obvious.

Patients with such conditions as strangulated hernia, meteorism of any type, intestinal obstruction, acute appendicitis, or diverticulitis are theoretically susceptible to complications if moderately high altitude must be attained in air evacuation. This reasoning may also apply to patients who have undergone recent gastrointestinal surgery in which the stomach or colon has been sutured. One should certainly consider the particular postoperative course of each patient and foresee the possible adverse effects of pressure changes on the suture line.

From the preceding discussions, it is possible to make the following generalizations that may be important in considering these patients for evacuation by air:

(1) Since the quantity of gas and the type of food ingested prior to flight may determine a difference in altitude tolerance as far as gastrointestinal symptoms are concerned, it seems reasonable to state that if, in the patient's experience, certain foods cause such symptomatic discomfort as distention, then, he should avoid these foods at ground level for at least 12 to 24 hours before a flight. Usually, a condition such as diarrhea, constipation, or other temporary gastrointestinal conditions will be aggravated and not relieved by ascent to altitude.

(2) When it is necessary to evacuate patients with gastrointestinal tract pathology, rectal tubes and stomach tubes should be available. It has also been recommended that, when patients have penetrating wounds or perforated ulcers of the stomach or intestine, use of the proper suction, as by the Wangensteen method, should be made to maintain intestinal tract decompression during flight. Occasionally, such simple meas-

ures as loosening tight belts, massage of the abdomen at altitude, and preflight lavatory hygiene are sufficient to prevent or relieve difficulties.

Very few, if any, symptoms have ever been reported as being of urinary bladder origin. It would seem that the bladder walls normally expand and contract in proportion to the urine content and, hence, there is very little or no free gas available for expansion at altitude. However, as a matter of speculation, a given patient with loss of bladder tonus, urinary retention, etc., could have difficulty if an increase in abdominal pressure were caused by expansion of gases in the gastrointestinal tract and this pressure were transmitted to the bladder. Obviously, recent bladder operations, fistulous connections, and temporary cystotomy with indwelling catheter could introduce sufficient air for expansion at altitude. If no arrangements for free release of the air were made, difficulties probably would arise.

Pathological Conditions of the Chest. There are a number of pathological conditions of the chest that may be responsible for a person's poor tolerance to evacuation by air.

Pneumothorax:

Although there are several types and classifications of pneumothorax injuries, all of them will have one thing in common. On ascent to altitude, any air trapped in the pleural cavity will expand and cause further collapse of the lung on the affected side and perhaps cause mediastinal shift. Analysis and understanding of several situations are important because they will provide a basis for explaining the effect of altitude on air in the pleural cavity.

A perforating injury of the chest wall allows air to enter the pleural cavity. This is an external pneumothorax, and if the defect is allowed to remain open, the air in the pleural space will be at atmospheric pressure (760 mm Hg at sea level). The presence of air at this pressure in the pleural space will prevent the lung from expanding during inspiration because there will be little or no difference between the air pressure on the outside of the body and the air pressure in the pleural cavity. Obviously, large openings may be more dangerous than small openings. Further, if the wound acts like a valve, allowing air to enter the pleural cavity but not leave it, then the air pressure in the cavity may rise above atmospheric and a "tension pneumothorax" results.

In some instances, the lung itself may become diseased so that there is erosion of a pulmonary bronchus. Under these conditions, the bronchus is in direct communication with the pleural space and air can enter the chest from the bronchus. This is an internal pneumothorax, but its effect, insofar as air is concerned, is no different from that of the external type. In both conditions, air at ambient pressure has entered the pleural cavity, limiting the expansion of the lung and, obviously, embarrassing respiration.

The important thing to remember is that, on ascent to altitude, gas in the pleural cavity will expand, and the expansion will be somewhat greater than that demanded by Boyle's Law for dry gases. The problem is much the same as that considered in the discussion of the gastrointestinal tract. When trapped gas in the pleural cavity expands at altitude, it will cause further compression of the lung on the affected side and may cause mediastinal shift or mediastinal flutter with each respiratory cycle. Because of this shift, function of the opposite lung may become impaired, and sudden death may result from impaired cardiac and pulmonary functions. Another possible, but less likely, complication is aero-embolism. Air trapped in the pleural space might expand and compress the affected lung's alveoli and, perhaps, tuberculous cavities so forcefully that air is forced from these spaces into the venous capillary blood vessels. Several studies have shown that a differential pressure of 80 or 100 mm Hg is needed to force air as bubbles from the alveoli into the blood stream.

Medical personnel should make certain that the proper instruments are at hand to aspirate air from the pleural cavity and, thereby, prevent air expansion at altitude. These instruments should be available under all circumstances because weather conditions are unpredictable and an unscheduled ascent to higher altitudes may become a necessity. These untoward effects may occur even though oxygen is used. This emphasizes that relief of hypoxia does not prevent the expansion of gas in the pleural cavity at altitude.

Mediastinal emphysema, arising from a direct puncture wound, perforation of the pharynx, esophagus, etc., could also produce serious effects on the circulation by causing pressure on the large veins which enter the chest. The expansion of this trapped mediastinal gas at altitude may result in further complications by exacerbating these pressure effects. Such patients certainly should not be evacuated by air unless a pressurized aircraft is available or unless an emergency situation demands immediate movement of the patient. In an emergency, the flight must be made at low altitude if a reliably pressurized aircraft is not available.

Tuberculosis:

Many military personnel with tuberculosis of varying degrees of clinical severity have been transported by air. Commercial aircraft have also transported thousands of tuberculous patients. There is no definite evidence that these patients were adversely affected by their exposure to altitude. However, each tuberculous patient to be evacuated by air must be considered a special case. The use of oxygen, special handling of coughed-up material, and the possibility of pneumothorax occurring during flight are considerations worthy of attention.

If moderately high altitudes (12,000 to 15,000 feet) must be attained during the flight, it is safest to use oxygen masks. A tuberculous lung may have a sufficient loss of surface area and restriction of movement by adhesions, so that symptoms of hypoxia would appear at altitudes lower than those in the case of a normal person. The use of oxygen may be especially indicated in tuberculous patients because, if hypoxia occurs, faster and deeper breathing could possibly cause hemorrhage by stretching healed lung fibrous tissue or the adhesions which are relatively common in chronic cases. Even though oxygen may be used, the apprehensive patient who becomes hyperpneic or the patient affected by moderately severe airsickness could possibly have a hemorrhage. This is also true of patients with bronchiectasis or esophageal varices.

The possible effects of gas expansion in body cavities have been discussed. It is important to point out again that, if air is trapped in a small cavity or in a small bronchus which is blocked, this air will attempt to expand at altitude. If the cavity has a rigid wall and does not readily allow an increase in volume, then the pressure inside the cavity or closed bronchus undergoes a relative increase at altitude. It is reasonable to believe that the expansion of gas in such a closed region or in and around a tubercle, under some circumstances, could liberate organisms into other areas of the lung. Material in the bronchi can be coughed up. This is not unusual in bronchiectasis or tuberculosis. It is obvious that disposable oxygen masks should be provided and other measures employed to prevent the spread of infective organisms.

Cranial Injuries:

Certain types of skull fracture cause injury extensive enough to result in the entrance of air into the brain case. This is particularly true if the fracture occurs in the bony wall between the sinuses, or ear, and the brain with a tear in the dura mater. In such cases, there may be a leakage of either clear or bloody cerebrospinal fluid to the outside. At the same time, of course, air can enter the skull. Because of blood clots and the possible valve-like action of damaged tissue, it is feasible that, in many instances, this air is relatively trapped and would expand at altitude if such a patient were evacuated in an aircraft.

The effects of such gas expansion could be expected to be far more serious than in other regions of the body because the brain is so rigidly inclosed that the gas attempting to expand could exert a considerable pressure. Harmful effects, and even death, may result from the expansion of intracranial gas.

It should be apparent from the preceding discussion that adverse effects of gas expansion may also be expected in the air evacuation of patients who recently had air artificially introduced into the skull or spinal spaces for purposes of encephalography or ventriculography. Similarly, brain tumors and cysts with spaces occupied by gas could produce symptoms of varying degree, depending upon the cabin altitude attained during the flight as well as the quantity of gas. One should be aware of the possible effects of altitude on such patients, and careful preflight evaluation should be made to determine the advisability of evacuating such patients by air.

It has been shown that, in the presence of brain concussion with an elevated cerebrospinal fluid pressure, there is a decreased oxygen saturation of the arterial blood. The latter hypoxemia could be alleviated by breathing oxygen. These findings provide a basis for advocating the use of oxygen equipment in the case of a patient with an elevated intracranial pressure who must be evacuated by air. A positive-negative pressure resuscitator should be used if there seems to be any danger of the patient's own respiration becoming embarrassed. The mean pressure during the respiratory cycle should be close to ambient pressure because higher pressures could further increase intracranial pressure.

Miscellaneous Conditions. Any collection of gas under the skin, as in subcutaneous emphysema, or in the muscles and skin, as produced by the anaerobic organisms, such as B. Tetanus or B. Welchii, may be expected to expand during ascent. Whether this expansion of subcutaneous gas would result in faster and wider dissemination of the organisms or toxins is problematical. Such a possibility exists, however, and should be carefully considered when the question arises regarding the advisability of evacuating these patients by air.

Dysbarism

At the altitudes used for air evacuation, symptoms of altitude dysbarism, such as bends and chokes, are not usually problems. However, one should be aware that persons with recently healed fractures can have moderately severe joint symptoms at low altitude. The occurrence of joint pains at these low altitudes suggests that other factors, such as hypoxia or vascular changes, are concerned in the production of "typical" bends pain—that is, in addition to "bubbles." Recent injuries, such as contusions, injection sites, etc., seem to become painful more frequently than old injuries.

Pregnancy

Patients who are beyond the 240th day of pregnancy normally are not accepted for evacuation by air. Exception may be made if movement is deemed essential. Theoretically, mild degrees of hypoxia at altitude, with changes in cardiovascular function and with, perhaps, a mild degree of change in acid-base balance because of hyperventilation, could cause an altered irritability of the uterus. Gas expansion in the stomach and colon could, perhaps, contribute to the total pressure of the already distended abdomen. It can be easily understood by those who have been moderately or severely airsick that repeated episodes of nausea, vomiting, and retching are undesirable symptoms, and would be especially undesirable if airsickness occurred during the last trimester of pregnancy.

Effects of Decreased Air Density

The effects of decreased air density are an important consideration in the evacuation of patients by air. The concepts are simple. Litter patients may require food and drink during flight. The reclining position is not conducive to efficiency in the act of swallowing. Consequently, there may be aspiration of a small amount of fluid or solid material into the trachea or bronchus.

Both at sea level and at altitude, the irritation of the respiratory passages caused by such foreign material results in reflex coughing. However, the effectiveness of the cough mechanism depends to a great extent, upon the density of air in the respiratory passages. Even at low altitudes, the air density has been sufficiently decreased so that the force of the expiratory phase of the cough is lessened. For this reason, the efficiency of the cough in removing such foreign particulate matter is decreased and the results may be disastrous.

Effects of Hypoxia

In general, the vulnerability of a patient to hypoxia at altitude would largely be a matter of the degree to which the patient cannot accommodate because of respiratory or cardiovascular pathology. This means that the respiratory apparatus, cardiovascular system, or both, fail to respond to the decreased oxygen tension at altitude. The patient is not as able to accommodate to the lower oxygen tensions as is the normal person.

Patients having pneumonia, emphysema, asthma, tuberculosis with extensive pulmonary adhesions, lung abscesses, or tumors, may already have the hypoxic type of hypoxia when they are at sea level. Ascent to altitude will add an additional degree of compromising hypoxia. Another case in point is that of the patient who has fractured ribs. It is obvious that the additional breathing response induced by the lowered oxygen tension at altitude would increase his discomfort by forcing him to breathe deeper and faster. Tight bandages may decrease his capacity to increase pulmonary ventilation.

All of these patients will normally benefit at altitude by the administration of oxygen. The benefit should be noticed quickly.

One simple fact which seems to be obvious, but nevertheless is often forgotten is: That, for oxygen administered by mask to be effective, the airway must be patent. The administration of oxygen by mask to a patient with a severe edema of the vocal cords or a severe degree of pulmonary pathology may not result in the desired oxygenation of the blood. Obstruction of the respiratory passages at any point between the mouth and nose to the alveoli will prevent the administered oxygen from reaching the pulmonary capillaries. Oxygen cannot, in these cases, be expected to provide relief from hypoxia.

At cabin altitudes attained during the usual or even unusual air evacuation flights, if the patient is initiating his own inspiratory efforts, there is little need for the additional oxygen that may be supplied by pressure breathing. The use of a pressure breather by patients at the low cabin altitudes of current aeromedical evacuation aircraft would be advantageous only if the patient were so severely ill that his spontaneous respirations ceased. Obviously, in this case, the pressure breather must be a resuscitator type of apparatus—that is, the instrument cycles whether or not the patient is initiating spontaneous respirations. One must understand that the instrument delivers a positive pressure which serves to inflate the lungs, and that this pressure is over and above the ambient or environmental pressure.

Air Transportation of Patients With Respiratory Insufficiency

In transporting patients with respiratory insufficiency, the physician is faced with two major problems: a. The criteria to be used in selecting patients for air transportation; and b. adapting currently used methods in the treatment of respiratory insufficiency to the limitations of air travel, to insure adequate care of the patient. The simplest way to discuss these problems is to separate the movement of these patients into three phases, namely, *preflight*, *in-flight*, and *postflight*.

Preflight:

This phase is the most critical. The selection of patients is of paramount importance. The adverse effect of physical activity on morbidity and mortality has been demonstrated. Thus, as a general rule, only a patient whose condition has stabilized and who is past the acute stage is acceptable. In exceptional cases, when respirator care is not available locally and cannot be taken to the patient, it may be necessary to transport such a patient to a respirator center.

This still leaves a large group of postacute or early chronic cases of poliomyelitis who may require transportation to a rehabilitation center, a larger hospital, or their homes. With respect to this group, the extent of the respiratory paralysis is important in determining how the individual patient will be transported and what margin of safety is available. A patient with only moderate respiratory paralysis, who is out of the respirator 8 to 12 hours a day, can usually be moved safely by ambulance or train for relatively short distances. More severely involved patients can be moved more safely and quickly by air.

It is the responsibility of the physician in charge of the patient being transported to make certain that the patient will receive the same quality of care in the aircraft as that provided in the hospital. This includes the proper instruction of those attending the patient regarding routine and special orders, and precautions to be taken to insure stability of the patient's well-being while in flight. All nurses should be alerted to the care of tracheostomies and the use of respirators. As a rule, a chest film is obtained within 24 hours prior to flight to assist in the evaluation of the patient.

In-Flight:

The in-flight phase presents other problems. The conditions of dryness of the atmosphere and the decreased oxygen tension at cabin altitude of 6,000 or 7,000 feet constitute hazards for the patient. The dry atmosphere causes thickening of the patient's secretions which makes their removal difficult. This can be combated by frequent suctioning, by intratracheal lavage with normal saline, and by humidifying devices. Decreased density of the air at altitude makes for less efficient functioning of the respirator. This, together with the decreased oxygen tension, may lead to serious underventilation. To avoid hypoventilation, the patient's tidal volume and respiratory rate are checked at frequent intervals, especially after any change in cabin altitude, and the respirator is readjusted as necessary.

According to the Radford nomogram, an additional 5% is added to the tidal volume for each 2,000 feet of cabin altitude above sea level. As a secondary check, the pulse and blood pressure are recorded at more frequent intervals between ventilatory measurements. A rise of over 20 mm mercury in the systolic pressure, or an increase of 20 to 30 beats per minute in the pulse rate may indicate hypoxia, which requires an immediate check of tidal volume and respiratory rate. The patient is given humidified oxygen if necessary, but an adequate ventilatory minute volume is essential whether oxygen is given or not. Patient anxiety related to the flight is allayed as far as possible by constant attendance and reassurance. Antinauseants are used if airsickness occurs, and often are given one hour before flight in selected cases.

Postflight. In the postflight phase, patient care remains under the supervision of the flight team until the patient has been placed in a respirator at the receiving hospital, and his ventilation, pulse rate, blood pressure, and general condition are considered satisfactory. (A certain number of these patients will develop complications after flight, such as fever, pneumonia, atelectasis, or excessive secretions. The incidence of such complications, however, has appeared to decrease considerably with the improvement in technique for air transport.)

By constant attention to the criteria for patient transportability and by continual refinement of in-flight procedures, a safe and practical method for transporting patients with respiratory insufficiency can be maintained.

Responsibilities of Originating Hospital:

The attending physician should have a tracheotomy performed in advance of the flight if there are any bulbar signs present, other than isolated facial nerve paresis.

The staff should be available to assist in the transfer of the patient from hospital equipment to a portable respirator.

The physician in charge of the patient should be available to brief the Air Force medical team on the patient's condition.

All medical records and clinical charts should be available.

The patient's baggage and equipment should be ready for movement.

Responsibilities of Destination Hospital:

Upon arrival of the patient, the receiving staff should be available and should include a physician who will become familiar with the case.

Personnel who are knowledgeable in the mechanics of the respirator should be available in the event there are mechanical difficulties requiring their attention.

Spare respirators should be available for emergencies or as replacements for malfunctioning units.

Hyperventilation Syndrome. Hyperventilation due to anxiety may result in respiratory alkalosis, with the patient exhibiting symptoms of blurring of vision, tingling of the fingers, and dizziness, which may progress to loss of consciousness, carpopedal spasm, and convulsions. Reassurance is important and may prevent this sequence of events. However, the physician must keep in mind that hypoxia may lead to hyperventilation which, in turn, may result in hypocapnia and the symptoms noted above.

Air Transportation of Patients With Cardiovascular Disease

The circulation has three compensatory mechanisms for increasing oxygen transport when hypoxic stresses are placed on the body. These mechanisms are: a. Increasing cardiac output; b. increasing the arterial-venous oxygen difference; and c. increasing the amount of circulating hemoglobin.

An important point to be made is that one of the compensating mechanisms for altitude hypoxia may be an increased cardiac output. At ordinary altitudes, the cardiac output may increase to about six liters per minute at rest. Even mild exercise at altitude could call for a further increase in cardiac output. Obviously, this means an increased strain on the heart and vascular system.

Patients with decompensating hypertensive cardiovascular disease, recent coronary occlusions, or angina pectoris should ordinarily be declared unacceptable for air evacuation except in emergencies when pressurized cabins are available. Most hypertensive patients can be transported safely; however, when factors such as apprehension and the presence of arteriosclerosis are considered, it may be better, sometimes, to err on the side of conservatism and not put the increased strain of altitude hypoxia on the diseased system. In any event, each case should be evaluated individually.

Anemia

The anemic patient differs from the normal patient in that he has a smaller total oxygen capacity and a smaller total oxygen content. One should not be misled by the fact that the anemic person can have the same oxygen saturation as the normal person. It is obvious, however, that the patient who is anemic by 50% has only half the amount of oxygen available to the normal person, even though the saturations are the same.

In a very anemic person, the tissues usually suffer because they do not remove 6 volumes percent of oxygen from the arterial blood, but perhaps only remove 2 or 3 cc of oxygen from each 100 cc of blood. Perhaps the tissues acclimatize, to get along on less oxygen. In any event, it is certainly obvious that there are limits on the extent to which his cardiac output, increased A–V difference, and mobilization of hemoglobin can help him to adapt to increased oxygen need during exercise or ascent to altitude.

As far as evacuation by air is concerned, it may be indicated that the anemic person be given oxygen.

As a general rule, if his body at rest is compensating for his anemia and keeping him in fairly good condition at sea level, then the administration of oxygen to such a person at moderate altitudes should keep him in just as good a condition at altitude as he was at ground level. By supplying him with oxygen at altitude, it is possible to make certain that what hemoglobin he does have is 100% saturated.

Sicklemia and Splenic Infarction

Since 1947, more than 30 cases exhibiting sicklemia and splenic infarction associated with aerial flights have been reported in literature. At present, a sickle cell preparation is required on members of ethnic groups known to have a high incidence of abnormal hemoglobin before flying status is approved. Consideration is being given, however, to establishing some form of electrophoretic hemoglobin analysis as a routine screening procedure.

Special Care of Eye Cases

The management of various diseases and injuries of the eye deserves special consideration because of its importance in helping to preserve useful vision or even the globe itself. The facts must also be known to make the proper selection of eye patients who may be evacuated safely by air.

It must be remembered that, ordinarily, the eye is a liquid-filled organ that is not subject to expansion changes. However, in injured and surgical cases, air may be present from injury or may have been surgically injected to reform the anterior chamber. In these cases, the patient must be flown at low altitudes to prevent the air from expanding and reopening the wound or breaking surgically sutured wounds. The alternative and best method is to transport the patient in a pressurized cabin with an especially low cabin altitude.

The effects of hypoxia are also important. Hypoxia produces dilatation of the retinal and choroidal vessels. A person who has had an intraocular hemorrhage may have a recurrence of this hemorrhage if not properly managed. Therefore, oxygen should be administered in such cases when attaining cabin altitudes of 4,000 feet and higher.

Hypoxia also produces a rise in intraocular tension. This is not desirable in any type of eye patient and can be prevented by the administration of oxygen.

A third important change in the eye caused by hypoxia is a decrease in pupillary diameter. This is particularly bad in injured or surgical cases where it is desired that the pupil remain dilated. This can also be prevented by the administration of oxygen.

A fourth point to bear in mind is the fact that the retina has the highest oxygen demand of any organ in the body. Therefore, in any type of choroidal/retinal disease or injury, oxygen should be administered, beginning at 4,000 feet, to prevent further damage to these tissues by the lack of oxygen. Sedation is important in relieving nervous tension in cases such as glaucoma.

In deciding whether the eye patient should be a seat or litter patient, the following may be helpful: The eye patient should be a litter patient if he has had: a. Recent intraocular wound; b. recent intraocular surgery; or c. severe eye disease of any type.

In managing the patient en route, care must be taken to prevent squeezing of the injured globe. Thus, dressings must be applied lightly and 0.5 percent tetracaine hydrochloride eye drops (Pontocaine) may be instilled every hour. *No eye ointment should be used in any open eye wound* since severe intraocular damage is often caused by entrance of the ointment through the wound. The patient should be heavily sedated with barbiturates. Morphine must not be administered without the permission of an ophthalmologist because it produces pupillary constriction.

The comatose patient must be carefully watched to prevent corneal drying. This can be prevented by closing the lids and holding them with moist cotton pledgets or by covering the eyes with X-ray paper after removing the emulsion. This paper, cut to proper shape, can be formed into a cone to be placed over the eye.

In caring for eye patients, the following danger signs must be watched for, and if they occur, they should be carefully noted on the patient's flight record: (1) Severe pain; (2) blurring or loss of vision; (3) visible intraocular hemorrhage; (4) change in pupillary size or shape; (5) photophobia; (6) protrusion of the globe; (7) extreme redness of the eyeball and conjunctiva; and (8) marked tenderness of the globe.

Decrease in Temperature at Altitude

In the case of patients at altitude, one should consider the type of aircraft used in air evacuation, and the range of temperatures likely to be encountered.

It is wise to make certain that the proper number of blankets and other necessary items are available for the protection of patients in the event that heating systems fail or high altitudes must be attained. Usually, the heating system is adequate, especially for patients situated forward in the aircraft. A common observation has been that the rear areas of some military aircraft are often not too well heated and, under some conditions, are uncomfortably cold.

Airsickness

Any type of motion sickness results in distress. There is reason to believe that patients transported by air are more likely to become airsick than other passengers. All grades of distress are encountered. Since airsickness may occur at any altitude, the problem is much different from that of hypoxia or dysbarism where decreases in altitude are usually effective in alleviating the condition. The most prominent symptoms of airsickness are nausea and vasomotor phenomena, such as pallor, sweating, chill, and actual vomiting.

The patients to whom vomiting is a particular danger are those with injuries requiring intermaxillary fixation. Usually, such patients are not transported by air unless the tie-wires are cut or replaced by elastic bands. When they are transported with tie-wires in place, they must be watched very closely and a proper instrument must be at hand to release the wires if necessary. They may also be further aided by being placed in a position that will facilitate removal of vomited material, which, as mentioned previously, is very important to all airsick patients.

Airsickness in severely ill patients or those with recent abdominal operations requiring extensive suturing procedures is highly undesirable, as the act of vomiting and retching causes increased tension on abdominal muscles and considerable increases in intra-abdominal pressure. It is reasonable to surmise that weak suture lines could be affected.

REFERENCES

The reader should insure the currency of listed references.

AFM 2–4, *Tactical Air Force Operations—Tactical Airlift.*

AFP 160–5–15, *Poliomyelitis.*

AFP 160–5–16, *Acute Renal Failure.*

AFP 160–6–9, *Care of Patients With Injuries of the Spinal Cord.*

AFP 161–16, *Physiology of Flight.*

AFR 160–12, *Professional Policies and Procedures.*

AFR 164–1, *Worldwide Aeromedical Evacuation.*

Chapter 20

THE MILITARY PUBLIC HEALTH AND OCCUPATIONAL MEDICINE PROGRAMS

The USAF Military Public Health and Occupational Medicine Programs employ many of the concepts and practices of clinical and preventive medicine for the promotion, protection, and improvement of health and the reduction of noneffectiveness due to disease and injury. These programs include the planning, supervision and coordination of all activities and measures designed for the attainment of these goals.

The Military Public Health and Occupational Medicine Service, an integral part of the Aerospace Medicine Service, is primarily responsible for the base-level Military Public Health Program. This Service is headed by a medical officer, aerospace medicine, who has additional duties as a Flight Surgeon. He supervises the personnel of this Service and coordinates with personnel of the other services whose activities contribute to an effective program. Enlisted men of the Preventive Medicine (907XO) career field provide vital assistance in the planning, conduct and evaluation of public health activities. The Service chief may call for assistance from clinical specialists, dentists, veterinarians, nurses, medical administrators, and biomedical specialists. A Public Health activity need not be under his direct supervision or be a primary responsibility of the Military Public Health and Occupational Medicine Service in order to contribute to the program. For example, the Pediatric Service is responsible for the Well-Baby Clinic and may be responsible for maintaining a local Poison Control Center. These are examples of Public Health activities that are not the direct responsibility of the Military Public Health Service.

Responsibilities

Effective Military Public Health and Occupational Medicine programs include activities in the following major areas:

Public Health Administration:

a. Formulation and supervision of programs for control and elimination of the causes of medical noneffectiveness.

b. Coordination of medical and engineering activities directed toward the prevention of injury and disease.

c. Evaluation of the health of military personnel through the analysis and interpretation of biostatistical records and reports.

d. Coordination of all Military Public Health activities with other interested and/or responsible civilian and military health agencies.

e. Interpretation and application of policies and directives concerning general and specific public health programs.

f. Preparation and submission of budgetary and materiel requirements for the operation of the services provided by these programs, for consideration by the Director of Base Medical Services.

Communicable and Preventable Disease Control:

a. Collection and analysis of statistical information on the incidence and prevalence of diseases communicable to man.

b. Epidemiological investigation of the occurrence or outbreak of diseases, and the initiation of appropriate action for control and prevention.

c. Monitorship of the immunization programs required by regulations and directives to insure a satisfactory state of individual and community protection.

Accident and Injury Prevention:

a. Investigation of the causes of death and injury resulting from ground and industrial accidents.

b. Provision of advice to Safety officers on medical matters relating to accidents and injuries.

c. Maintenance of liaison with athletics and recreation personnel concerning the medical aspects related to the use of equipment, physical condition of participating personnel, and conditions and practices conducive to safety.

Bioenvironmental Engineering:

a. Bioenvironmental engineering is the application of engineering principles to the control of man's environment. At base level, a Bioenvironmental Engineer is assigned to the Aerospace Medicine Service and participates primarily in the areas of Military Public Health and Occupational Medicine. It is the Bioenvironmental Engineer who identifies a potentially hazardous situation, such as that involving water pollution, air pollution, high-intensity noise, ionizing radiation or toxic chemicals, evaluates the hazard through detailed study, and designs a control system. The Bioenvironmental Engineer can be of assistance to the Flight Surgeon by insuring that Medical Service programs are established to maintain surveillance over public health problem areas.

b. The Bioenvironmental Engineer generally serves as the Medical Service representative on Construction Review Panels and Facilities Utilization Boards, and reviews all projects involving new construction or modification of existing facilities.

c. When a Bioenvironmental Engineer is not assigned to a base, services for the establishment of a program or survey of specific problem areas are available from the major command surgeon's office and/or from HQ AFLC on a consultation basis, in accordance with AFR 161-17.

Environmental Pollution Control. The entire nation is becoming more concerned with environmental pollution as it may affect the air we breathe and the water we drink. As part of a national effort to abate pollution, the entire Federal Government has been directed by law to assume a role of leadership in this undertaking. The Federal Water Pollution Control Act and the Clean Air Act, as amended, have resulted in the issuance of Executive Orders, DOD directives and, ultimately, Air Force regulations placing certain responsibilities upon the US Air Force Medical Service.

a. AFR 161-22 specifies that the Surgeon General, USAF, will be primarily responsible for coordinating environmental contamination matters with other Federal agencies and health authorities, and for establishing standards and criteria for protection of health and welfare of Air Force personnel. In addition to the programs of major commands that direct their attention to the identification and elimination of environmental pollution sources at all Air Force bases, certain commands are charged with additional responsibilities which direct their efforts toward providing consultation services and accomplishing necessary field investigations and research programs.

b. In the area of waste water treatment requirements, the standard is secondary treatment. Any degree of treatment less than secondary requires the approval of HQ USAF and the Federal Water Pollution Control Administration (FWPCA), Department of Interior. The Air Force is required to comply with directives on pollution standards published by the US Public Health Service (USPHS), Department of Interior or State and local pollution abatement agencies. If State or local standards are not prescribed or are less stringent than those of the Air Force, Health, Education and Welfare (HEW), or FWPCA, the standards of FWPCA will apply.

c. Representatives of the Air Force Medical Service serve on the DOD Environmental Pollution Control Committee, along with members of the US Army and Navy. Problem areas requiring joint efforts are considered and solutions made available to major commands.

d. The AFLC Regional Environmental Health Laboratories have keyed their support efforts to providing consultation services to major commands and bases not possessing the necessary instrumentation or trained personnel.

As can be seen from the above, the Air Force Medical Service has a vital role in supporting the national effort to reduce environmental pollution of our natural resources.

Occupational Health:

a. Under established Federal laws, the Air Force assumes responsibility for the provision of adequate protection of military and civilian personnel against exposure to occupational hazards. Provision of outpatient care and hospitalization, at Government expense, to civilian employees injured or ill as a direct result of occupational activity, is required by the Federal Employees Compensation Act. Emergency care of personnel with nonoccupational, on-the-job medical and dental health problems is authorized under Pub. L. 79-658. Definitive care for these illnesses is provided by the employee's private physician.

b. The conduct of preemployment, placement, and periodic physical examinations is a necessary prerequisite in the assignment and management of military and civilian personnel. The Occupational Medicine Service should provide for the monitoring of these examinations, completion of associated forms, and transmittal of these forms and other information to the proper personnel offices, both military and civilian.

c. The Occupational Medicine Service monitors hospital admissions and outpatient clinic visits for evidence of illnesses and injuries related to occupational exposure. Liaison and rapport with clinic and hospital physicians, together with requirements for formal reporting of occupational diseases and injuries, insure accurate and adequate data collection. Chapter 21 contains information concerning specific occupational illnesses and exposures.

d. Separate facilities or offices for treatment of civilian employees by the Occupational Health Service are neither feasible nor required at most Air Force bases. However, such facilities are required at some of the larger industrial bases and are the responsibility of the Aerospace Medicine Service which monitors staffing, programming and management.

e. Additionally, the Occupational Medicine Service provides health education and counseling, occupational hazard evaluations, bioenvironmental engineering surveys, personal protective equipment monitoring, and liaison with community medical and public health personnel.

Community Environmental Control. The health of Air Force personnel depends, to a great extent, on the provision of a safe water supply, adequate refuse and waste disposal, insect and rodent control, food services sanitation, and adequate and comfortable housing. Military Public Health and Occupational Medicine personnel coordinate, supervise, survey and, in some instances, provide control of these services. The necessity for medical concern in these essential services is apparent in view of epidemics that have occurred as a result of unhealthy conditions existing in these areas due to improper maintenance of health standards.

Epidemiology. This is the field of medicine that concerns itself with the relationships of the various factors and conditions which determine the frequency and distribution of all illnesses. Modern techniques and methods employed in epidemiology are applicable to acute and chronic illnesses, accidents, and injuries. Investigation of a disease condition or an epidemic is based upon observations and data concerning three main factors in the propagation or spread of the disease, namely, *the source, the means of spread,* and *the susceptible individual or group.* To properly assess the public health needs of the military community, it is essential that one understand the application of the terminology and techniques related to epidemiology. Specialized assistance for the investigation of communicable disease outbreaks and for special environmental health surveys can be obtained by consultation with the USAF Epidemiological Laboratory

(AFSC), Lackland AFB, Texas, or one of the Epidemiological Flights in oversea areas.

Nuclear, Biological and Chemical Defense. Each Air Force base has plans for activities in these areas of defense, including medical support. Medical input is required for disaster control and actions to be taken in defense of overt or covert nuclear, biological or chemical accidents or incidents. Activities under the Military Public Health Program include formulation of policy, compilation of plans, and coordination of medical measures for the prevention of illnesses and injuries resulting from chemical, biological, and radiological warfare and for detection and interpretation of the presence of agents used in such warfare.

Health Education. This is an important activity under the Military Public Health and Occupational Medicine Programs. Planning, development, and administration of a base-wide public health education program to promote better health and improve individual and community attitudes toward disease and injury, are vital functions of these programs. To a certain extent, every contact made between medical personnel and the community affords an opportunity for health education. Further, evaluation and correlation of all health activities provide a strong basis for such education. Material, films, brochures, pamphlets, etc., pertaining to health education are available from numerous Government and private agencies at a nominal cost.

Nutrition. The importance of adequate nutrition to the military mission and morale should never be underestimated. Medical participation in menu planning, food services sanitation, nutrition education, and special feedings in-flight and during hospitalization, require the supervision and assistance of the Military Public Health Service.

Research. The planning, initiation, supervision, and accomplishment of research and studies on the causes of noneffectiveness and on the control, prevention, and treatment of all injuries and diseases may require inputs from the Military Public Health Service. Significant, timely, and valuable research may be performed at the base level by energetic and interested physicians and engineers. (See AFR 169-6.)

Medical Intelligence. AFR 200-3 defines the concepts of medical intelligence, the need for and scope of the Medical Intelligence Program, the sources of medical intelligence, and the responsibilities under the program. Under all conditions and especially during wartime, the Flight Surgeon can provide valuable inputs and interpretations related to the Air Force Intelligence system.

Assistance Available

There are several sources of information available to the Flight Surgeon that will assist him in carrying out his responsibilities under the Military Public Health and Occupational Medicine Programs.

Air Force Directives. A library of appropriate manuals, pamphlets and regulations is maintained by the Aerospace Medicine Service. These directives primarily fall under the 160 and 161 Series and are listed in AFR 0-2.

Libraries:

a. The base medical facility library should contain current textbooks, standard references, and medical periodicals dealing with the fields of Military Public Health and Occupational Medicine.

b. The resources of other governmental and civilian medical libraries may be used on an interlibrary loan basis.

c. The National Library of Medicine, Bethesda, Maryland 20014, provides prompt service, without charge, to officers on active duty. Material such as bibliographies on specific medical subjects and copies of articles in current or past issues of medical journals can be made available upon request. Direct communication is authorized and encouraged.

Consultation:

a. The Chief, Military Public Health and Occupational Medicine, should take advantage of the training, experience, and talents of other members of the base medical service and of personnel assigned to other base organizations. The Chief of Aerospace

TABLE 20–1. CONSULTATION SOURCES FOR MILITARY PUBLIC HEALTH AND OCCUPATIONAL MEDICINE

SOURCES	SERVICES AVAILABLE	AUTHORITY	COMMUNICATION
Major commands and numbered air forces	1. Consultation	AFM 161-2	1. Aerospace Medicine Reports (RCS: 1-HAF-M7)
	2. Consultation services of Bioenvironmental Engineers.		2. Letter requesting assistance thru channels. 3. TWX (if urgent). 4. Telephone.
USAF School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas	1. Furnish information on medical problems involving noise. 2. Diagnostic Hearing Center.	AFR 160-3	1. Letter to USAFSAM, Brooks AFB TX 78235. 2. Consultation request per SF 513 to USAFSAM.
	3. Consultation on Military Public Health problems and Occupational Health.		3. Letter to USAFSAM (SMTP).
Regional Environmental Health Labs (AFLC):	1. Consultation services of Medical Officers, Engineers and others trained in Occupational Health.	AFM 161-2 AFR 161-17	1. Direct communication to Laboratory; info cy to Surgeon, AFLC.
a. Kelly AFB TX 78241 b. McClellan AFB CA 95652 c. USAF Hosp, APO New York 09220	2. Determinations of Biological Fluids: a. Lead and mercury in urine and blood. b. Fluoride and thorium in urine. c. Cholinesterase in serum and erythrocytes. d. Blood carboxyhemoglobin.	AFR 161-17	2. Samples sent to Regional Environmental Health Laboratory.

TABLE 20-1. Continued

SOURCES	SERVICES AVAILABLE	AUTHORITY	COMMUNICATION
	3. <u>Determination of Environmental Samples:</u> a. Lead. b. Mercury. c. Fluorides. d. Zinc. e. Cadmium. f. Beryllium g. Arsenic. h. Chromic acid. i. Trichloroethylene and other halogenated hydrocarbons. j. Dust counts. k. Particle size determination. l. Bromides. m. Selenium. n. Silica. 4. Determination of contaminants in aircraft oxygen systems (Kelly AFB only). 5. Other chemical analyses upon special request.		
	6. Water pollution control (Kelly AFB). 7. Air pollution control (McClellan AFB).	AFR 161-22	3. Base to major command to REHL.
USAF Radiological Health Laboratory (AFLC), Wright-Patterson AFB, Ohio	1. Determinations on biological and/or environmental specimens, including soil: a. Radium. b. Plutonium. c. Tritium. d. Strontium.	AFR 161-17	1. Direct communication to USAF Radiological Health Laboratory (HWR), Wright-Patterson AFB OH 45433.

TABLE 20-1. Continued

SOURCES	SERVICES AVAILABLE	AUTHORITY	COMMUNICATION
	e. Uranium. f. Radon breath analysis. g. Gross alpha particle count. h. Gross beta particle count.		
	2. Film Badge Monitoring.	AFR 161-11	2. Exposed film and communications direct to USAF Radiological Health Laboratory (SGHW), Wright-Patterson AFB OH 45433.
Advisory Center on Toxicology, Washington, D. C.	1. Provide advice and information relating to the adverse effects of chemical substances on man, animals and plant life. Examples: Solvents, fuels, insecticides, rodenticides, etc.	AFR 161-18	1. Letter thru channels to HQ USAF (AFMSPA) Wash DC 20333.
AMRL (AFSC), Wright-Patterson AFB, Ohio	1. Furnish information on most recent protective equipment, and on other developments that will support the noise control program.	AFR 160-3	1. Letter to 6570 AMRL, Wright-Patterson AFB OH 45433.
Public Health Services	1. Act as liaison between Armed Forces and local health agencies. 2. Cooperation with Armed Forces in regard to health and sanitation in extra-military areas. 3. Consultation on communicable diseases; insect and rodent control. 4. VD investigation.	AFR 160-1 AFR 161-4 AFR 161-7	1. Letter to Regional Public Health Director thru command or numbered air force Surgeon. 2. Letter to US Dept of Health, Education & Welfare, PHS, Bureau of State Services, Communicable Disease Center, Atlanta GA 30322. 3. Submission of PHS 9.2936 (VD) as prescribed in AFR 161-7.

TABLE 20–1. Continued

SOURCES	SERVICES AVAILABLE	AUTHORITY	COMMUNICATION
Joint Utilization of Certain Armed Forces Laboratory Facilities	1. Army Area Medical Laboratories: a. Perform all types of clinical laboratory procedures as well as examination of meat, dairy products and other foods. b. Conduct epidemiological investigations. c. Provide limited training for laboratory officers and technicians in special fields. 2. Navy: a. Conduct epidemiological investigations, special sanitary surveys, and perform supporting laboratory examinations (not including routine clinical laboratory tests). 3. Air Force: a. Conduct epidemiological investigations. b. Conduct entomological surveys. c. Conduct occupational health surveys.	AFR 160-62	1. Request for lab test on submitted specimens. Senior medical officer makes direct request to CO of Laboratory. 2. Requests for services involving travel of personnel between departments is submitted thru channels to Dept of AF. Telephone or telegraphic requests may be made in an emergency with later written confirmation submitted thru channels.
TAC, Langley AFB, Virginia	1. Insect control by aircraft.	AFR 91-22	1. Initial request is sent thru channels to major command for approval. Approved request is forwarded to TAC, Langley AFB VA 23365.
Armed Forces Epidemiological Board (AFEB), Washington, D. C.	1. Provide scientific and research assistance and advice on matters pertaining to problems in Preventive Medicine, Epidemiology, Tropical & Internal	DOD Directive 5154.8 AFEB	1. Emergencies: Telegraphic (TWX) request from Director, Base Medical Services to HQ USAF (AFMSPA) Wash DC 20333.

TABLE 20–1. Continued

SOURCES	SERVICES AVAILABLE	AUTHORITY	COMMUNICATION
	Medicine, Pathology, Immunization, etc., towards the control and prevention of disease and injury.		2. Normal: Thru normal channels to HQ USAF (AFMSPA) Wash DC 20333. 3. Overseas: Same, except under approval of major command with info to HQ USAF (AFMSPA) Wash DC 20333.
Armed Forces Pest Control Board (AFPCB), Forest Glen Annex, Walter Reed Army Institute of Research, Washington, D. C.	1. Provide consultation on prevention of arthropod-borne diseases and control of arthropod and rodent vectors and reservoirs of disease, and provide entomological information services.	DOD Directive 5154.12 AFPCB	1. Letter thru channels to HQ USAF (AFMSPA) Wash DC 20333.
USAF Epidemiological Laboratory, Lackland AFB, Texas	1. Provide personnel laboratory services consultation and support services on epidemiological problems. 2. Provide consultation and personnel services to: a. Conduct entomological surveys. b. Determine effectiveness of insecticidal applications. c. Perform specialized studies on Epidemiology of Arthropod-borne Diseases. d. Identify insect specimens. e. Investigate significant disease outbreaks on request (hospital staphylococcus outbreaks, etc.). f. Forensic toxicology.	AFR 161-12 USAF Epi Lab AFR 161-1 (d) AFR 161-17 (f)	1. On occurrences or conditions requiring reporting under para 5-30, AFM 168-4. 2. Telegraphic (TWX) report from Director, Base Medical Services, to HQ USAF (AFMSPA) Wash DC 20333, with type of assistance requested, and info cys to USAF Epi Lab and major command. 3. Oversea Activities: Same, except thru major command. 4. Insect specimens for identification may be sent direct to Laboratory.

Medicine or the Director of Base Medical Services who is trained in Aerospace Medicine can serve as a very valuable consultant on the management of public health activities and the solution of related problems. Through the cooperative efforts of the Base Civil Engineer and the Bioenvironmental Engineer, considerable assistance can be provided on problems related to water purification, waste disposal, construction of facilities, and control of air and water pollution. Food services personnel, the Veterinary Service officer, and the hospital dietitian can be of assistance on problems concerned with food service, food handlers' hygiene, obesity control, and special crew feeding.

b. The offices of the surgeons of numbered air forces and major commands often have specialists in Aerospace Medicine, Public Health, Bioenvironmental Engineering, Radiobiology, etc., who are available for telephonic or written communication. Regular staff visits by these specialists may be utilized for the purpose of seeking solutions to problems or disseminating policy guidance and procedures.

c. Additional sources of consultation available are listed in table 20-1.

Chapters 21 through 24 of this manual contain additional information and guidance for planning and carrying out the programs defined and discussed in this chapter.

Chapter 21

OCCUPATIONAL MEDICINE IN THE AIR FORCE

The purpose of this chapter is to provide the Flight Surgeon with concepts to aid him in the evaluation of occupational medicine problems occurring both on the ground and at altitude.

GENERAL PRINCIPLES OF AVIATION AND OCCUPATIONAL TOXICOLOGY

The Industrial Air Force

A major factor of the unprecedented upsurge of industry in this country, particularly in the chemical, electronic, and mechanical fields, has been the need to support our domestic needs as well as our national defense requirements. With industrial development and diversification come the inevitable problems of controlling environmental hazards to health. The Air Force is one of the largest "customers" for the newest chemical and electronic agents, and thus assumes the responsibility for protecting its personnel and the public from potential health hazards arising from Air Force operations.

Hazard Control by Team Effort

The control of industrial toxic or physical hazards depends upon the combined efforts of a team of specialists trained to predict hazards to health on a sound, scientific basis. They act to establish limits of exposure (threshold limit values (TLVs)) and control the exposure of employees and neighboring populations within such limits by the most effective means. Such action usually involves the installation of engineering control measures with periodic evaluation of atmospheric and biological concentrations of harmful substances and their metabolic products. This team frequently consists of the flight surgeon, the bioenvironmental engineer, and the ground safety specialist.

Need for Medical Judgment in Hazard Control

Because of the diversification of industrial operations at even the smallest Air Force facilities, it is essential that good judgment be applied in deciding the nature of actual or potential hazards and the degree of medical or engineering control necessary. Our aim is to aid in the accomplishment of the mission in the most efficient way with the least cost in manpower, materiel, and money. Desirable byproducts of such a program are better working conditions, health, morale, and productivity of the work force that are advantageous to both the Air Force and the employee.

The Flight Surgeon as an Occupational Medicine Practitioner

The Flight Surgeon is often the person best qualified to study problems of occupational medicine at Air Force bases. If he will study the everyday toxic problems that exist in the industrial areas or on the line, he will be in a far better position to evaluate the problems of toxic materials in flight.

Need for Caution in Diagnosing Industrial Disease

Before getting into some of the specific problems of toxicity that exist in Air Force operations at present, it is necessary to interject a word of caution concerning the diagnosis of occupational disease. The physician who has had minimal experience in the diagnosis of conditions produced by toxic materials often will make unfounded and erroneous guesses as to the cause of a disease condition when a history of working with toxic materials is presented. It is imperative to remember that there is much to lose and little to gain by "snap" diagnoses in such cases. There are many diagnostic aids in toxicology, the same as there are in other forms of clinical medicine, and such aids should be used along with consultation, when required.

A physician might hesitate to diagnose syringomyelia without the consultation of a neurologist. In contrast, he may be willing to stake his professional reputation on a case of lead poisoning although he had never seen such a case previously. Once an erroneous diagnosis has been entered on the medical record or related to the patient, the seed has been planted for an unfair compensation case and, quite often, a compensation neurosis. Therefore, caution should be exercised in diagnosing occupational disease.

Criteria for Diagnosis of Industrial Disease

Generally, the following criteria must be met for a diagnosis of occupational disease to be made:

a. The substance to which the person is exposed must be capable of producing the disease.

b. The time-dose relationship and the time between the exposure and the appearance of the illness must be adequate.

c. Other causes of the condition must be ruled out, if possible, in differential diagnosis.

The Air Force has provided for consultation in occupational health just as it provides for special support in other medical specialties.

Availability of Consultation

There are three Air Force Regional Environmental Health Laboratories that provide specialized laboratory support to the USAF Occupational Health Program, worldwide. These laboratories are operated by AFLC at McClellan AFB, California, and Kelly AFB, Texas, and by USAFE at Wiesbaden AB, Germany.

This consultation service is provided under AFM 161–2 and AFR 161–17. Further services are available in the area of radiological health through the USAF Radiological Health Laboratory, at Wright-Patterson AFB, Ohio.

HQ AFLC acts as the advisor to the Office of the Surgeon General, USAF, in evaluating potential hazards to health from new physical, chemical, or biological industrial agents, except when used as warfare agents.

The Concept of Threshold Limit Values

The majority of industrial agents capable of producing hazards to health fall into two general categories: chemical and physical. Considerable effort has been expended by both private and governmental research agencies to delineate the concentrations of chemicals that produce a potential health hazard to exposed workers. These levels (threshold limit values) are primarily based on time-weighted average concentrations to which the typical employee may be exposed on an 8-hour day, 5-day week schedule for his productive life without producing a health hazard. AFP 161–2–1 gives current threshold limit values for toxic chemicals.

Toxicity between agents cannot be compared on a quantitative basis solely with reference to their threshold limit values. A brief consideration of the basis for establishing the TLV in a few examples will demonstrate how prone to error such a comparison would be. In the case of solvents, if there is known to be chronic toxicity, the TLV is quite low—*e.g.*, 25 ppm for benzene and 10 ppm for carbon tetrachloride. If, on the other hand, chronic toxicity has not been found in animal or man, the TLV is based upon acute effect, such as narcosis—*e.g.*, 100 ppm for trichloroethylene and 200 ppm for chlorobromomethane. In both cases, adequate precautions must be taken to prevent overexposure, and there is little or no difference in the control ventilation needed. The reliance on the "safety" of a solvent simply on the basis of the comparison of its TLV with that of another is, thus, likely to cause error.

To apply TLVs intelligently, one must determine the following types of information about the agent:

a. Vapor pressure and density.

b. Solubility.

c. Particle size.

d. Means of absorption.

e. Acute effects.

f. Chronic effects.

g. Metabolic and excretory mechanism. *For example,* silicosis may result from excessive, repetitious exposure to free silica of particle size less than 10 microns. Particles larger than this do not reach the pulmonary alveoli since they are trapped in the upper respiratory tract and removed by ciliary action. In fact, most particles five to ten microns in size are also removed from the air in the upper airway. Silica particles three to five microns in size are deposited in the mid-respiratory tract while many of the smaller particles are deposited directly in the alveoli. Submicron particles remain suspended and are usually exhaled. Silicosis attributed to living along the beach or in the desert where the sand is composed of pure-free silica would be most unusual because particle size is too large.

In the case of lead sulfide, the miners of "galena" are not known to develop typical inorganic lead poisoning or plumbism because the lead sulfide is so extremely insoluble in the gastrointestinal tract that it passes through without being absorbed. On the other hand, free lead, lead oxide, or other soluble lead compounds are quite readily absorbed via the gastrointestinal tract and capable of producing recognizable clinical disease.

Use of Special Laboratory Tests

Considerable care is required in the selection of laboratory tests to aid in implementing an occupational health program. *For example,* there are still some persons who continue to use stipple cell counts or coproporphyrin determinations alone as a means of detecting overexposure to lead. It is true that such tests of altered physiology may be of some value if evaluated in the light of other findings (atmospheric concentration of lead, urine and blood lead, etc.), but when used alone, they may be worse than nothing in that negative results may give a false sense of security. In the case of inorganic lead, the most important periodic tests are the atmospheric concentration of lead and the urinary lead level. In cases where the urinary lead is elevated, a blood lead determination should be obtained. The urinary lead level is most sensitive to fluctuations in ambient air lead concentrations while blood lead level is far more reliable to indicate accumulation of toxic amounts of lead.

Great care must be taken to prevent contamination of the specimens, and "positive" laboratory results should be repeated. Air Force clinical laboratories are usually unable to perform the necessary analysis involving microtechniques and special equipment; thus, all such specimens should be forwarded to an environmental health laboratory for analysis. The altered physiology of the employee should never be used as the primary indicator of hazardous levels of toxic materials in the working environment. Proper environmental monitoring through sampling procedures is, of course, the method of choice.

Estimation of Toxicity From Chemical Formula

The estimation of toxicity on the basis of chemical formula alone is unreliable. Experience has demonstrated that some compounds that should be exceedingly toxic, on the basis of formula, are not; whereas, others which, on the same basis, would be expected to be ralatively harmless, have caused serious symptoms.

Interpretation of Literature

Probably no other field of medicine possesses such a wide variation in quality of medical literature. Some of the finest scientific work has been done in the field of occupational medicine and, yet at the same time, one can find examples of the poorest. The Flight Surgeon should bear this in mind as he reviews the literature, and not hesitate to request assistance in the event his decision may be expected to have far-reaching consequences.

AIR FORCE OPERATIONS

Ground Operations and Exposure

Eighty percent of the Air Force's total effort is spent in ground support of airborne activities. Air Force operations in which toxic agents have been found are listed in table 21-1. A similar table should be prepared by the Flight Surgeon who has industrial medical responsibilities. The Flight Surgeon and the Bioenvironmental Engineer are responsible for controlling health hazards found in Air Force operations and should survey the working environment, studying any potentially hazardous situations they encounter by actual measurement of the quantity of potentially hazardous material present in the atmosphere.

Technical Orders

Technical orders usually outline safety and health aspects of procedures prescribed. Valuable aids in the study of such operations are military specifications which often outline the constituents of solvents, rust inhibitors, oils, greases, gasoline and other fuels, paints, paint thinners, dope, carbon remover compounds, and hand cleansers.

Survey Equipment

Survey equipment used in studying environmental contamination is listed in Table of Allowance (TA) 906, Set, Environmental Health. The equipment it contains will allow study of the work atmosphere for common gases and vapors, ionizing radiation, and air movement. In addition, there are sound and light meters and temperature and humidity instruments available. Bases where this equipment is not available may request assistance from a regional environmental health laboratory through their major command headquarters.

Survey Evaluation

It is to be emphasized that survey equipment be used only by trained personnel if valid and reliable results are to be obtained. Sensitive instruments in the hands of inexperienced personnel with inadequate professional training may produce erroneous results or misinterpretations, as well as damaged instruments through improper use. As a consequence, proposed corrective engineering control measures may be inadequate or excessive. All survey results, whether atmospheric or biological, require thorough interpretation if effective control measures are to be applied.

TOXIC GASES, FUELS AND VAPORS

The Flight Surgeon should be especially aware of the toxic gases and vapors that may be found in crew and passenger compartments of aircraft. Although care has been taken in aircraft manufacture and design, unusual circumstances may allow gases and vapors to permeate occupied areas. When this occurs, dangerous physiological effects may result from a combination of toxicity, concentration, and prolonged exposure.

Exposure to toxic chemicals in flight is usually brief, and when toxic effects are discovered, they are usually acute. Therefore, it is essential that flying personnel have a sound understanding of the toxic chemicals that may be encountered in aircraft. It is important that they develop an awareness of the possible presence of the toxic vapors and that they be able to institute appropriate emergency measures when necessary.

Contamination of the atmosphere of an aircraft may result from the following: exhaust gases, hydraulic fluid mist, fuel vapors, coolant fluid vapors, oil vapors, anti-icing fluid vapors, fire extinguishing fluids, cargo, and the thermal decomposition products of electrical insulation.

Exhaust Gases in Piston Engines

The composition of exhaust gases varies widely, depending largely upon the type of engine and the fuel-air ratio at which the engine is operated. Carbon monoxide, methane, and hydrogen result from incomplete combustion of the fuel. As the fuel-air ratio decreases and the completeness of combustion increases, the percentage of carbon dioxide in the exhaust gas rises, with a corresponding decline in the percentage of carbon monoxide. Conversely, as the mixture

TABLE 21-1. CONTROL OF PRINCIPAL TOXIC AGENTS FOUND IN AIR FORCE OPERATIONS

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Aero-Repair	Solvent dry cleaning Fed Spec PS-661a Small quantities other toxic agents such as toluene, acetone, amyl acetate, lead, ethyl alcohol, butyl alcohol, ethyl acetate, butyl acetate, petroleum naphtha, turpentine, carbon monoxide, caustic cleaners, greases.	Dermatitis Pulmonary inflammation	General exhaust or good natural ventilation Local exhaust ventilation for cleaning inside of planes Protective hand creams Strict personal hygiene Good housekeeping Covered solvent containers Protective clothing
Assembled Engine Cleaning	Solvent dry cleaning Fed Spec PS-661a Rust inhibitor	Dermatitis Pulmonary irritation	Local exhaust ventilation Protective hand creams Protective clothing such as gloves, aprons, and boots
Battery	Lead Sulfuric acid Sulfur dioxide	Dermatitis Pulmonary irritation	General or local exhaust ventilation Personal protective clothing Isolation of process
Blacksmith	Carbon monoxide Sulfur gases Radiant heat Dust	Dermatitis Anoxemia Heat exhaustion	General and local exhaust ventilation Personal protective clothing Good housekeeping
Carburetor and Ignition	Solvent dry cleaning Fed Spec PS-661a Trichloroethylene	Dermatitis Pulmonary irritation Renal damage Central nervous system damage	Local exhaust ventilation Covered solvent containers Protective hand creams
Electrical Shop	Degreasers, solvents, oxides, selenium beryllium sulfate, carbon tetrachloride	Dermatitis, Lung and Liver damage, malignant ulcers.	Adequate ventilation both general and local, which may include booths, respirators, proper handling and disposal of fluorescent lighting tubes.
Electroplating	Sodium cyanide Cadmium oxide Oxides of nitrogen Hydrofluoric acid Other chemicals which may be used are lead carbonate, copper sulfate, nickel sulfate, nickel chloride, phosphoric acid, acetic acid, caustic soda, chromic acid	Dermatitis (acid and caustic burns) Effects of hydrogen cyanide Edema of lungs Plumbism Conjunctivitis Chrome ulcers	Local exhaust ventilation (horizontal slot type preferable) General exhaust ventilation Isolation of process Protective cream Separate rooms and ventilation systems for acid solutions and cyanide solutions Personal protective clothing

TABLE 21–1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Engine Block Test	Carbon monoxide Solvent dry cleaning Fed Spec PS-661a Noise Oils, greases Gasoline, jet fuel	Dermatitis Anoxemia Temporary partial hearing losses Pulmonary irritation	Positive pressure ventilation of control room Local exhaust of oil return system Protective hand creams Protective ear plugs Proper design and location of block test buildings
Engine Cleaning	Solvent dry cleaning Fed Spec PS-661a Caustic cleaners removing (creosols and ortho-benzene)	Dermatitis Pulmonary irritation Possible CNS, kidney and liver damage	Local exhaust ventilation Good natural ventilation Strict personal hygiene Protective creams Protective clothing
Engine Disassembly	Solvent dry cleaning Fed Spec PS-661a Oils, greases Other volatile solvents	Dermatitis	Good general or local exhaust ventilation Strict personal hygiene, protective clothing, protective creams
Fire Protection and Crash Rescue	Fire extinguishants C. B., CO^2 Carbon Tetrachloride, heat, thermal decomposition, products of the extinguishants.	Acute narcosis, asphyxiation, liver and kidney damage, heat exhaustion, lung irritations.	Proper training, ventilation of filling booths, use of respirators and masks. Strict control and supervision in the use of carbon tetrachloride as extinguishant.
Foundry	Silica Carbon monoxide Metal fumes Excessive heat	Silicosis Anoxemia Heat exhaustion Metal fume fever	General and local exhaust ventilation Approved type dust respirators Good housekeeping Use of nonsilica parting compound
Fuel System Repair Shops	Solvents, gasoline, jet fuel, methylethylketone, ethylene dichloride, petrol naphtha.	Dermatitis, narcotic effects, eye irritation, liver and kidney damage, acute anesthetic effects.	Thorough indoctrination in precautionary measures. Use of protective equipment (hand creams, respirators, local exhaust ventilation).
Heat Treating	Sodium cyanide Carbon monoxide	Dermatitis Effects of hydrogen cyanide Anoxemia	General and local exhaust ventilation (individual exhaust pipe for cyanide) Strict personal hygiene
Hydraulic	Solvent dry cleaning Fed Spec PS-661a Hydraulic fluids	Dermatitis	Good general or local exhaust ventilation Protective hand creams Protective clothing

TABLE 21-1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Hydraulic and Pneudraulic Shops	Solvents, alcohol hydraulic fluid.	Dermatitis, aplastic anemia, atrophy of optic nerve, liver and kidney damage.	Careful indoctrination of personnel; hand creams, respirators, adequate ventilation.
Insect and Rodent Control Section	Various economic poisons (Insecticides and rodenticides). Solvents, kerosene.	Skin irritants, dermatitis, systemic poisoning (Liver necrosis, Nephritis, convulsions, tremors from spinal cord and brain damage.)	Skin protected by protective clothing. Safety goggles (chemical), respirators.
Instrument Repair	Solvent dry cleaning Fed Spec PS-661a Naphtha Small quantities of miscellaneous organic solvents	Dermatitis	Local exhaust ventilation for solvent spray booth Good general ventilation Covered solvent containers Protective hand creams Protective clothing
Insulation	Toluene Diisocyanate (TDI) Tetrafluoroethylene (Teflon) Thermal products	Dermatitis, Pulmonary irritation Fume fever	Precautionary measures Personal hygiene Good housekeeping Exhaust ventilation Personal protective clothing
Jet Engine Test Stand & Jet Engine Runup.	Excessive noise exposure.	Loss of hearing, damage to the cochlea, damage to the middle ear, rupture of the tympanic membrane. Fatigue, loss of muscular coordination. G. I. symptoms.	Earplugs, muffs or helmets—Both helmets and plugs are recommended where the exposure is high and over a long period of time. Noise suppressor devices (when feasible)
Luminous Dial Painting & Repair	Alpha and beta particles Gamma rays Radon gas Organic solvents	Radiation poisoning Dermatitis	Thorough indoctrination in precautionary measures Rigid enforcement of proper techniques Strict personal hygiene
Machine Shops	Cutting oils and greases Misc. dusts	Dermatitis	Strict personal hygiene Protective creams Local exhaust ventilation of dusty processes

TABLE 21-1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Metal Cleaning Shop	Solutions and vapors of acids Hydroxides Trichloroethylene Methylene chloride Potassium permanganate Fed Spec PC-111a	Dermatitis Mucous membrane irritation Narcosis CNS, liver and kidney damage	Local exhaust ventilation (horizontal slot type preferable) General exhaust ventilation Personal protective clothing Eye wash and safety shower
Metal Inspection (defects)	Penetrant dyes (Zyglo process) Industrial X-ray	Dermatitis Acute & chronic radiation effects	Strict personal hygiene Protective creams Personal protective clothing and equipment (See "X-ray and Ionizing Radiation.")
Minor Repairs	Solvent dry cleaning Fed Spec PS-661a Trichloroethylene Small quantities of miscellaneous organic solvents Caustic cleaning materials Oils and greases	Dermatitis Mucous membrane irritation CNS, liver and kidney damage	Local and general exhaust ventilation Protective hand creams Personal hygiene Personal protective clothing and equipment
Missile Operations (See AFM 127-201 and AFM 160-39.)			
Paint & Dope (brush and spray painting)	Paint thinner & dope containing misc. organic compounds, such as benzol, toluene, acetone amyl acetate Ethyl or butyl alcohol Butyl acetate VM and P naphtha Turpentine Lead	Dermatitis Possible plumbism Blood changes and nervous symptoms	Exhaust ventilated paint spray booth Supply air respirator Chemical cartridge respirator Protective hand cream Isolation of process Closed solvent containers and separate storage of bulk paint and solvents
Parachute, Leather, Rubber and Textile Shop	Solvents, caustic cleaners, naphtha, methylethylketone, ethylene dichloride.	Dermatitis, narcotic effects, acute anesthetic effects, eye irritations	Same as "Fuel System Repair."
Plexiglas	Small quantities ethylene dichloride	Dermatitis Anesthetic effect	General exhaust or good natural ventilation Covered solvent containers

TABLE 21–1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Plumbing Shop	Aircraft & vehicle fuels and sludges, including tetraethyl lead	Dermatitis CNS damage	Supplied air respirators and local exhaust ventilation for tank cleaning General exhaust ventilation Personal protective clothing
P. O. L. Hydrant Refueling	Gasoline, J. P. fuels, Methanol.	Dermatitis, Plumbism, eye irritations, optic atrophy, acute anesthetic effects.	Orientation of personnel in prescribed precautions, use of protective equipment such as chemical safety goggles, full face shield. Respirators may be required in high concentration. Protective clothing, deluge type shower—bubble type, eye washings, blankets.
Precision Measuring Equipment Laboratory (PMEL)	Ionizing radiation Mercury spills	Neurological disturbances (See "X-ray and Ionizing Radiation.")	General exhaust ventilation Flowers of sulfur (sublimed sulfur) for Mercury spills (See "X-ray and Ionizing Radiation.")
Pre-Dock Aircraft Washings	Moisture, cold, kerosene and detergents.	Chilling, dermatitis, nose, throat and eye irritations.	Using ample protective clothing. Protective skin creams, respirators.
Propeller	Solvent dry cleaning Fed Spec PS-661a Small amounts of oils, greases and trichloroethylene Paint remover	Dermatitis Possible narcotic effect and renal damage	Good general and local exhaust ventilation Protective hand creams Protective clothing
Radiator and Tank Oil Coolers	Lead Compound carbon remover Caustic cleaning solution Solder and solder fluxes Greases and oils Solvent dry cleaning	Dermatitis Plumbism CNS, liver and kidney damage	Local exhaust ventilation General ventilation Protective hand cream Protective clothing and equipment.
Refilling Fire Extinguishers	Carbon tetrachloride Carbon dioxide Chlorobromomethane	Dermatitis Narcotic effect CNS, kidney and liver damage	Local exhaust ventilated booth Good general ventilation Personal protective clothing and equipment
Rubber Tank Repair	Toluene Ethylene dichloride Small quantities of other materials, such as ethyl acetate, ethyl alcohol, methylethylketone, benzol, petroleum naphtha	Dermatitis Narcotic effect Nervous symptoms	General and local exhaust ventilation Protective hand creams Personal protective clothing and equipment.

TABLE 21-1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Sandblasting (abrasive cleaning)	Dust produced by pure silica sand organic abrasives, and steel shot	Dermatitis Pneumoconiosis (the higher the free silica content of the dust, the greater its hazard)	Proper maintenance of sandblast cabinets and equipment US Bureau of Mines approved respiratory protective devices (supplied air helmets) Use of nonsilicious abrasives when possible
Sewage Disposal Plant	Methane, chlorine, H^2S and Infections of skin and G. I. tract.	Asphyxiations, Lung irritations, dermatitis, conjunctivitis and anemia.	Training—Use of respirators or gas masks and immunization.
Sheet Metal Shops	Deficiency of illumination, noise. Source — mechanical injury.	Dermatitis, Injury Eye strain Hearing loss	Properly designed work room, protective clothing, frequent washings, ear defenders.
Spark Plug Cleaning	Pure silica sand Solvent dry cleaning Fed Spec PS-661a Trichloroethylene	Dermatitis Silicosis Narcotic effect CNS and renal damage	Local exhaust and general ventilation Protective hand creams Personal protective clothing and equipment
Teletype and Other Communication Maintenance	Methyl chloroform (1-1-1 trichloroethane)	Dermatitis CNS depressant	Good general or local exhaust ventilation
Vapor Degreasing	Trichloroethylene Perchloroethylene	Narcotic effect CNS, liver and kidney damage	Proper operation of vapor degreasers Locate degreasers away from drafts Keep degreasers covered when not in use Local exhaust ventilation when other corrective measures fail Supply air respirators and personal protective clothing when cleaning degreasers
Water Plant	Chlorine gas, lime, soda ash, fluorides.	Lung, nose, eye irritations, dental flurosis, caustic effects on skin.	Use of respirators, gas masks and good personal hygiene.
Welding	Radiant energy Metal oxides including lead, iron, cadmium Gaseous decomposition products of red coatings Other toxic substances in small quantities, such as oxides of nitrogen, fluorides, and carbon monoxide	Dermatitis Flash burns of eyes Metal fume fever Heat exhaustion Edema of lungs Anoxemia	Protective helmet, shield, gloves, and apron (electric weld) Isolation of process General ventilation Local exhaust ventilation (always when producing cadmium or lead fumes) Portable or permanent black shield to protect adjacent workers

TABLE 21-1. Continued

Process Where Found	*Toxic Agent*	*Health Hazards*	*Control Measures*
Woodworking Shops	Wood, dust, glue, mechanical injury	Poor illumination and safety devices. Toxemia from Phenolic resins and paint solvents. Allergic skin reactions.	Good ventilation and adequate lighting. Little or no contact with the skin. By using gloves, aprons and respirators, and adequate hand washing facilities.
X-ray and Ionizing Radiation	Ionizing Radiation	Acute and chronic radiation sickness. Beta burns, adverse effect on the bones, lungs and blood, gonads, skin and mucus membranes. *a.* Skin-Brittleness and ridging of the nails. *b.* Hands—Increased susceptibility to chafing. *c.* Blunting or leveling of the finger ridges. *d.* Dryness and epilation. *e.* Changes in nail fold capillaries in the way of disordered pattern. *f.* Eyes—Cataracts from neutrons.	Control of time of exposure; provision of shielding, respirators, etc. Use of distance to maintain total radiation dose below the permissible levels.

becomes richer, the carbon monoxide of the exhaust gas increases.

Exhaust Gases in Jet Engines

The exhaust gases from jet engines contain over 95% air, the balance being essentially carbon dioxide. The probability of toxic levels of carbon monoxide being present is remote. However, since jet fuel is permitted to contain considerably more sulfur than is gasoline, irritating concentrations of sulfur dioxide and aldehydes may appear in the exhaust gas.

All new aircraft models must meet rather rigid specifications for freedom from contamination by carbon monoxide before they are accepted by the Air Force. However, since exhaust gases may get into the crew and passenger compartments by several ways, aircraft which were originally free from contamination or contained only slight amounts of carbon monoxide at the initial test, may deteriorate from wear and tear or change as a result of structural modifications introduced while in service. Periodic tests are required to reveal such contamination and serve as a check on the adequacy of the maintenance service.

Carbon Monoxide (CO)

Carbon monoxide should be suspected when fumes suggestive of heater or exhaust sources are noted. Since the gas is odorless, it is necessary to use one of the various carbon monoxide detectors when its presence is suspected. It can be detected readily in air by commercial carbon monoxide indicators or by a colorimetric method which has been developed by the National Bureau of Standards (Detector, carbon monoxide, Type B–1, FSN 6685–490–2010). The threshold limit value of carbon monoxide in Air Force cockpits is 50 parts per million.

Tests of cabin air give an indication of the conditions only at the particular moment when the air is tested. These conditions vary according to the length of time the engine has been running, the fuel-air ratio, the ventilation, and the position in the cabin from which the sample is taken. From a practical standpoint, the carbon monoxide content of the pilot's blood is a more important consideration as this represents the cumulative effect of the gas to which he has been exposed. Blood gas analyses are difficult, and if they are to be considered reliable, they must be performed by experienced technicians. The average hospital clinical chemistry laboratory is rarely capable of providing uniformly reliable results with blood gas techniques.

The Environmental Health Laboratories are equipped and have trained personnel to make blood carboxyhemoglobin determinations on sampled blood. In handling blood samples, precautions must be taken to prevent loss of carbon monoxide. Tubes must be completely filled, covered, and protected from light. In evaluating blood concentrations, it is important to consider the "normal" values, especially in smokers in whom the control values of carbon monoxide may be as high as 8% saturation.

Failures in the exhaust system have been responsible for several cases of seepage of carbon monoxide into the cockpit. In some instances, this failure has consisted of cracks in the exhaust stacks from excessive vibration. In others, the gas has gained access to the cockpit through worn packings around the collector rings. In aircraft equipped with exhaust heaters, contamination has occurred from wear of the intensifier tube assembly and from defects caused by enemy fire. Because of the latter possibility, pilots are advised not to use their exhaust heaters in combat.

Carbon monoxide is absorbed exclusively through the lungs. The rate of uptake depends upon the rate and depth of respiration, the concentration of carbon monoxide in the air, the duration of exposure, the blood volume and hemoglobin concentration, and the degree of saturation of the blood with carbon monoxide.

At rest or during light activity, about 50% of the inspired carbon monoxide is taken up by the blood initially. Of the gas which actually enters the alveoli, a much larger proportion, about 90%, is retained by the blood. Carbon monoxide has a greater affinity to hemoglobin than does oxygen and the rate of dissociation of carboxyhemoglobin is much slower.

The affinity of human hemoglobin for carbon monoxide is 210 to 300 times its affinity for oxygen. The formation of carboxyhemoglobin is favored by a reduction in the concentration of oxygen in the air and by an increase in the temperature or humidity. When any of these changes occur or the amount of physical activity is increased, the toxic effects of carbon monoxide occur more quickly.

Strictly speaking, carbon monoxide is not a poison. It acts rather as a tissue asphyxiant, accomplishing this function by a twofold action. First, by combining with the hemoglobin to the partial exclusion of oxygen, it interferes with the uptake of oxygen by the blood. Secondly, it causes a shift to the left of the oxygen dissociation curve of the remaining hemoglobin and, also, makes the curve less S-shaped and more hyperbolic (Haldane effect). Thus, hemoglobin which is partially saturated with carbon monoxide clings to its oxygen with increased tenacity with the result that less oxygen is liberated to the tissues. Both phenomena combine to produce hypoxia.

The structures which are most sensitive to anoxia, such as the central nervous system and the myocardium, are the first to be affected. In cases of acute poisoning, there are fewer symptoms since unconsciousness soon occurs. The greatest individual variation in symptoms is encountered in those cases in which the exposure has been less severe, yet more protracted and repeated.

Blood concentrations of carbon monoxide up to 10% saturation usually cause no symptoms under ordinary conditions (sea level, moderate physical activity, normal hemoglobin). With increasing blood saturation, symptoms appear usually in the sequence shown in table 21-2. The approximate times required for the appearance of symptoms with exposure to varying concentrations of carbon monoxide are shown in table 21-3.

The hazard of carbon monoxide increases sharply at altitudes above sea level. Mild degrees of hypoxia caused by increasing altitude and small amounts of carbon monoxide, each of which might be harmless alone, may, when combined, cause serious impairment of efficiency as a result of the additive hypoxic

TABLE 21-2. SYMPTOMS OF VARIOUS BLOOD CONCENTRATIONS OF CO AT SEA LEVEL

% Saturation	Symptoms
Less than 10	None
10	No appreciable effect except shortness of breath on vigorous muscular exertion.
20	Shortness of breath, even on moderate exertion; slight headache.
30	Decided headache; fatigability; irritability; impaired judgment.
40 to 50	Headache; confusion; collapse; fainting.
60 to 70	Unconsciousness; respiratory failure, and death if exposure is prolonged.
80 or more	Rapidly fatal.

(Reproduced from "Noxious Gases and the Principles of Respiration Influencing Their Action," ACS No. 35, by Y. Henderson and H. W. Haggard, by permission of Reinhold Book Corporation, a subsidiary of Chapman-Reinhold, Inc., New York, 1943.)

TABLE 21-3. EFFECTS OF VARIOUS CONCENTRATIONS OF CO IN AIR AT SEA LEVEL

PPM CO in Air	Effects
200	Possibly headache, mild frontal in 2 to 3 hours.
400	Headache, frontal, and nausea after 1 to 2 hours; occipital after 2 1/2 to 3 1/2 hours.
800	Headache, dizziness and nausea in 3/4 hours; collapse and possibly unconsciousness in 2 hours.
1,600	Headache, dizziness and nausea in 20 minutes; collapse, unconsciousness, possibly death in 2 hours.
3,200	Headache and dizziness in 5 to 10 minutes; unconsciousness and danger of death in 30 minutes.
6,400	Headache and dizziness in 1 to 2 minutes; unconsciousness and danger of death in 10 to 15 minutes.
128,000	Immediate effect; unconsciousness and danger of death in 1 to 3 minutes.

(Reprinted from "Industrial Toxicology," Second Edition, by Hamilton and Hardy, with permission of Paul B. Hoeber, Inc., Medical Book Department of Harper & Brothers, New York. Copyright 1949.)

effects. If a minimum blood O_2 saturation of 85% is required for the maintenance of flying efficiency, the ceiling at which flights may be made without oxygen is reduced to below 10,000 feet when small concentrations of carbon monoxide are present.

For example, a concentration of 0.01% (100 ppm) CO, relatively safe at ground level, reduces the oxygenation of the blood by 10.5% and at 10,000 feet, is superimposed on the reduced blood O_2 saturation occurring at this altitude, resulting in a dangerous state of hypoxia. This condition is even more serious in aircrew members who are heavy smokers with an elevated base line of 8% carbon monoxide saturation. Smoking may reduce a crew member's altitude tolerance as much as 5,000 feet.

Above 10,000 feet, when the demand oxygen is used, the dangers of carbon monoxide decrease with increasing altitude. This is due to the fact that, as a higher percentage of oxygen is obtained from the demand system with increasing altitude, less of the atmospheric air and, consequently, less carbon monoxide are obtained. Above 30,000 feet, where the demand system furnishes 100% oxygen, the inhalation of carbon monoxide is completely prevented.

Some of the carbon monoxide taken up by the blood is converted chemically to other substances in the body; the remainder is excreted as carbon monoxide in the expired air. Yet, for practical purposes, the rate of elimination depends upon the respiratory volume and the percentage of oxygen in the inspired air. Breathing pure air at sea level, after absorption of moderate amounts of carbon monoxide, clears the blood of about one-half of the gas in 1 hour. Elimination is practically complete within 8 hours. Increased amounts of oxygen accelerate the rate of excretion of carbon monoxide. When pure oxygen is breathed following exposure to the gas, the elimination time is reduced to an hour or less. Hyperbaric oxygen has been effectively used in the therapy of persons asphyxiated by carbon monoxide.

When flying personnel suspect the presence of carbon monoxide in the plane because of either the odor of exhaust gas or untoward symptoms, such as headache, nausea, dizziness or dimming of vision, they should turn off exhaust heaters if in use and don oxygen masks with the Auto-mix of the regulator turned to the "Off" or "100% Oxygen" position. By so doing, they will insure themselves of protection from carbon monoxide by excluding all cockpit air.

If breathing is weak or has ceased, definitive treatment of carbon monoxide asphyxia by medical officers should include artificial respiration, the administration of 100% oxygen, and the application of warmth to the patient placed at rest. Indicated supportive measures should be initiated as well.

Aviation Gasoline

Aviation fuel is a complex mixture of aliphatic and aromatic petroleum hydrocarbons and special additives, such as tetraethyl lead and xylidine, in varying proportions. Grades and types of aviation fuel used by the US Air Force are listed in table 21-4.

One gallon of gasoline completely evaporated will form approximately 30 cubic feet of vapor at sea level. These vapors are heavier than air. Since they are readily absorbed by the pulmonary epithelium, their toxicity is a matter of practical importance. Untoward reactions have occurred among flying personnel who have been exposed to volatilized gasoline.

The concentration of gasoline vapors that can be tolerated by man is far below that required to produce combustible or explosive mixtures with air. If the concentration of gasoline vapor in air is high, absorption by the lungs may be extremely rapid and symptoms may appear after only a few minutes of exposure. Even one-tenth of the concentration necessary to support combustion or to form an explosive mixture is harmful if inhaled for more than a short time, and causes dizziness, nausea, and headache. Large amounts act as an anesthetic and cause unconsciousness.

The tolerance level value for exposure to vapors of ordinary gasoline is about 500 parts per million or 0.05%. However, because of its content of aromatic hydrocarbons, aviation gasoline is probably at least twice as toxic. Furthermore, because of the precise and frequently complicated activities which flying personnel are required to perform, even small amounts of gasoline vapors in the plane must be considered dangerous.

When vapors are detected, there is a psychological excitability which, when coupled with a toxicological excitability, can cause poor judgment on the part of the various responsible aircrew members and have probably been the cause of some accidents attributed to pilot error. The vapors from gasoline, not being unpleasant, do not cause enough concern to the aircrew. It should, therefore, be emphasized that, when gasoline

TABLE 21-4. GRADES AND TYPES OF AVIATION FUEL USED BY THE AIR FORCE

Specification	Grade	Tetraethyl Lead (cc/gal) Maximum	Aromatics
MIL-F-5572	80 Octane 91/96 Octane 100/130 Octane 115/145 Octane	0.5 4.6 4.6 4.6	3-15% 3-15% 3-15% 3-15%
MIL-J-5616	JP-1	0	0-20%
MIL-F-5624a	JP-3 JP-4	0 0	0-25% 0-25%
MIL-3-3056	Motor Vehicle Gasoline	3	Varies by Process of Manufacture
VU-M-561	II	3	(None required by specification)

vapors are noted, the aircrew should use 100% oxygen to avoid inhalation of these fumes.

The symptoms and pathologic changes induced by gasoline are caused by both its irritant and its lipolytic actions. Acute poisoning is marked by burning of the eyes, lacrimation, and severe cerebral symptoms, such as restlessness, excitement, disorientation, disorders of speech, visual difficulties, and convulsions leading to coma and death.

Tetraethyl Lead

Tetraethyl lead, which is used as an antiknock substance, is very toxic. Poisoning from this substance may occur by absorption through the intact skin as well as by inhalation of its vapors. Unlike inorganic lead, tetraethyl lead, an organic compound, primarily has a central nervous system effect in cases of poisoning. Insomnia, mental irritability, and instability are noted. Lead encephalopathy with acute mania develops. In less dramatic cases, sleep may be broken with restlessness and terrifying dreams. Other symptoms include nausea, vomiting, muscle weakness, tremor, myalgia, and visual difficulty.

The amount of tetraethyl lead in aviation gasoline, about 4.6 cc per gal, is so small that a lead hazard through normal handling is remote. There is usually no requirement to periodically determine the lead content in the urine of workmen who refuel airplanes. Poisonings encountered in the Air Force have been the result of entering gasoline storage tanks containing concentrated amounts of tetraethyl lead within the accumulated sludge. Also, maintenance, such as welding, buffing, and grinding on engines which have burned leaded gasolines, can result in significant exposure to lead compounds.

JP Fuels

JP fuels, as used by the Air Force, are classified in three grades: JP-1, which is essentially paraffins similar to kerosene and containing up to 20% naturally occurring aromatics; JP-3, which is a mixture of one-third fuel oil, one-third kerosene, and one-third gasoline and containing up to 25% naturally occurring aromatics; and JP-4, which has a narrower distillation range with up to 25% naturally occurring aromatics.

Unlike aviation gasoline, JP fuels do not contain tetraethyl lead.

The recommended threshold limit value for JP fuel vapors has been set at 500 parts per million. Toxic effects occur below explosive levels; therefore, a toxicological problem exists even in the absence of a fire hazard.

Inhalation of vapors can result in slight narcotic effects similar to those of other hydrocarbon vapors. The vapors can cause conjunctivitis. JP fuels may contain more toxic aromatics than aviation gasoline and, therefore, should be handled with the same precautions.

Hydraulic Fluid

Two types of hydraulic fluid are currently in use in the Air Force: (1) Fluid, hydraulic, petroleum base, Spec No. MIL-O-5606, and (2) Fluid, hydraulic, castor oil base, Spec No. 3586C.

Oil, hydraulic, aircraft, petroleum base, is the hydraulic fluid that is used in virtually all US Air Force aircraft at the present time. There is only a very small usage of the castor oil base hydraulic fluid, primarily in certain trainer aircraft.

Important differences exist between the two types of hydraulic fluid with respect to the toxicity of their constituents. Fluid covered by Spec No. MIL-O-5606, consists, essentially, of a mineral oil base plus a viscosity index polymer and 0.5% tricresyl phosphate. Both of these substances are of relatively low volatility and their vapors possess a low toxicity. On the other hand, Spec No. 3586C contains, in addition to a castor oil base, diacetone, butyl cellosolve, ethylene and propylene glycol, and octyl and isoamyl alcohols in varying proportions.

The volatile constituents, especially butyl cellosolve, the glycol derivatives, and the alcohols, are toxic when inhaled. The alcohols, for example, are about 12 times as potent a narcotic as ethyl alcohol and, in addition, cause considerable irritation of the eyes and respiratory tract as well as headache and vertigo. The toxic effects of butyl cellosolve vapors also include irritation of the eyes and respiratory tract, headache, vertigo, and impairment of judgment and vision. Experimental animals have been killed within a few hours by a single exposure to air containing 3 mg per liter (about 700 ppm) of butyl cellosolve.

The toxic effects from inhaling the vapors of this hydraulic fluid are accentuated by increasing temperature or altitude which serves to increase the concentration of the vapors.

Coolant Fluid Vapors

Coolant fluid for use in liquid-cooled engines consists of ethylene glycol diluted with varying amounts of water, up to 80% according to the specific aircraft type. A small quantity of an inhibitor, designated as NaMBT, is present in the ratio of about 1 to 2,000.

Ethylene glycol is toxic when ingested. Although fairly volatile, it does not exert any important toxic effects through inhalation of its vapors. Even after continued exposure to ethylene glycol vapors over a period of several months, no deleterious effects result except moderate irritation of the respiratory passages. No instances of intoxication from coolant fluid vapors in flight have been reported.

Oil Fumes

The oil hose connections in airplanes consist of various types of adjustable clamps in contrast to the pressure-type connections used in the hydraulic system. Hose clamps occasionally break or come loose. When oil escapes on hot engine parts, smoke is often formed and finds its way into the cockpit. Several cases have been reported in which hot fumes were breathed during flight, and the symptoms that developed were similar to those of carbon monoxide poisoning, including headache, nausea, and sometimes vomiting, in addition to irritation of the eyes and upper respiratory passages. The specific chemical compounds responsible for these symptoms are not clearly defined but probably include methyl and ethyl aldehyde, acrolein, and paraformaldehyde which are the principal breakdown products of lubricating oil.

OTHER OCCUPATIONAL HAZARDS

Fire Extinguishants

There are two chemicals commonly used in aircraft as fire extinguishants. Two are used in the fixed systems: carbon dioxide, Spec No. 14069, and chlorobromomethane (CB), Spec No. 14163. Hand extinguishers on aircraft contain carbon dioxide or chlorobromomethane. CB has replaced carbon tetrachloride in hand extinguishers used on aircraft.

Carbon Dioxide. The initial effect of inhalation of carbon dioxide is noticed in concentrations of about 2%; breathing becomes labored and the total volume is increased. Depth of respiration is markedly increased at 4%. At 4.5 to 5%, breathing becomes labored and distressing to some people. Other effects at or near maximum tolerance for voluntary subjects are failure of compensatory reactions at concentrations of 5 to 10%, and marked deterioration and inability to take steps for self-preservation at concentrations exceeding 10%.

Carbon dioxide absorption will result in excitement, headache, vertigo, dyspepsia, drowsiness, weakness, dizziness, and muscular weakness. High concentrations may result in coma or death.

Chlorobromomethane (CB). This is a narcotic agent of moderate intensity but of prolonged duration. Therefore, it is apparent that acute exposures to chlorobromomethane should be avoided. Exposure to high concentrations of the vapor causes such effects as staggering, uncoordination, stupor, confusion, headache, nausea, and dizziness. Chronic toxicity is very low and adverse effects may not be expected from repeated exposures below .01% (100 ppm).

In contrast to the intensity of the narcotic action, the acute exposure to chlorobromomethane is less liable to cause necrosis of the liver, as observed with carbon tetrachloride, although it may produce fatty degeneration of the liver. The chronic toxicity of chlorobromomethane is definitely lower than that of carbon tetrachloride. The decomposed vapor is much more toxic than the undecomposed vapor. When CB is heated to decomposition, it emits highly toxic fumes of chlorides and bromides that are irritating and damaging to the lungs. Accumulations of these fumes within small spaces, such as aircraft cockpits, can lead to serious consequences.

Missile Fuels and Oxidizers

Health hazards from propellant fuels and oxidizers and safe handling procedures are outlined in various publications. However, several basic principles do bear emphasis. First, adequate safety precautions, based on an understanding of the hazards of the materials to be handled, are of primary and utmost importance. Secondly, rapid and adequate self aid and first aid following exposure to missile fuels can eliminate or vastly reduce subsequent medical treatment. Finally, the principles of mass casualty treatment for chemical or physical burns are applicable to the therapy of exposed missile fuel handlers.

Radar

Radar generators which, in certain cases, may have associated health hazards from ionizing and/or microwave radiation, are covered in other publications.

Ionizing Radiation

One area of industrial technological development has been in the use of ionizing radiation either from an X-ray source or from radioactive isotopes. This poses the problem in occupational medicine of possible personnel exposure. Industrial X-ray units may be employed on a base to examine aircraft structures for evidence of metal fatigue. The Flight Surgeon must insure that personnel working with such equipment are included in an effective monitoring program and that the equipment is used safely. Current directives provide the necessary guidelines in establishing and maintaining an adequate program.

Laser/Maser

Lasers (optical masers) are employed both in the industrial/research setting of the Air Force and operationally. Each individual type of laser has hazards peculiar to it, but all possess in common the severe eye hazards. AFR 161-24 contains guidance on the problems, hazards, and responsibilities with regard to laser operations. As additional data are accumulated in hazards in laser operations, specific Air Force publications will be issued.

Hazardous Noise Exposure

On most Air Force bases, there is a variety of equipment that can be a source of hazardous noise exposure to both military and civilian employees. The Occupational Medicine Program must insure that a program similar to the one proposed in chapter 5 of this manual, and by AFR 160-3, is fully implemented and supported.

Eye Hazards

Employees working with drill presses, grinders, sanders, and other similar types of machinery are exposed to a potential hazard of eye injury from flying debris. Additionally, many other occupational groups are exposed to potential eye hazards. To protect its employees, the Air Force supports the Occupational Vision Program (AFR 160-112). The Flight Surgeon must work closely with ground safety personnel in supporting this program. The importance of prevention as being preferred to treatment is paramount in considering eye injuries.

General Principles of Therapy

Safety manuals on emergency treatment of occupational overexposure usually advise immediate removal from exposure, self aid or first aid, and calling a physician. Therapy of massive overexposure to toxic chemicals is unsatisfactory at best.

It is extremely important that the responsible physician get the most precise, quantitative information possible on the time, degree, and duration of exposure. Such information should be made a permanent part of the medical record.

Care should be taken not to discharge a patient on the basis of "no abnormal findings" if he has been exposed to a pulmonary irritant. Pulmonary edema may occur up to 48 hours after exposure. Physical exertion often precipitates such attacks. Latent periods are also described prior to onset of convulsions from tetraethyl lead and decaborane. It is always safest to place the person on strict bed rest (in the hospital) with close medical and nursing supervision for a 24 to 48-hour period or longer. Some deaths from tetraethyl lead have occurred from self-injury—*e.g.,* jumping out of the window; thus, constant observation is necessary in such cases.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, Harry G., Toxicology in Aviation, Chapter 25, *Aerospace Medicine,* Baltimore, Williams and Wilkins Co., 1961.

Hamilton and Hardy, *Industrial Toxicology,* 2nd Edition, Harper and Brothers, New York, 1949.

Henderson, Y. and Haggard, H. W., *Noxious Gases and the Principles of Respiration Influencing Their Action,* 2d Edition, Reinhold Publishing Corp., New York, 1943.

Johnstone, R. T. and Miller, S. E., *Occupational Diseases and Industrial Medicine,* W. B. Saunders Company, Philadelphia, 1960.

Patty, Frank A., *Industrial Hygiene and Toxicology,* Vols I and II, Second Revised Edition, Interscience Publishers, Inc., New York, 1958 and 1963.

Sax, N. Irving, *Dangerous Properties of Industrial Materials,* Reinhold Publishing Corp., New York, 1957.

Schwartz, L., Tulipan, L., and Birmingham, D. J., *Occupational Diseases of the Skin,* Third Edition, Lea and Febiger, 1957.

Aviation Toxicology, Committee on Aviation Toxicology, Aeromedical Association, The Blakiston Company, New York, 1953.

AFM 160-25, *Engineering Data, Preventive Medicine and Occupational Health Program.*

AFM 160-39, *The Handling and Storage of Liquid Propellants.*

AFM 161–2, *Conducting the Aerospace Medicine Program.*

AFP 161–2–1, *Threshold Limit Values for Toxic Chemicals and Certain Electromagnetic Radiations.*

AFP 161–2–2, *Health Precautions for Welders and Solderers.*

AFP 161–2–3, *Toxicology of Trichloroethylene.*

AFP 161–2–4, *Toxicology of Ozone.*

AFP 161–6–4, *Health Hazards and Their Control in Metal Degreasing.*

AFR 160–3, *Hazardous Noise Exposure.*

AFR 160–112, *Occupational Vision Program.*

AFR 160–124, *Application for Radioisotope Licenses.*

AFR 160–132, *Control of Radiological Health Hazards.*

AFR 161–10, *Precautionary Measures for Handling Solvents.*

AFR 161–17, *Environmental Health, Forensic Toxicology, and Radiological Health Professional Support Functions.*

AFR 161–24, *Laser/Maser Hazards.*

Chapter 22

WATER CONTROL

The Base Civil Engineer Officer is responsible for the supervision and accomplishment of all work entailed in providing a safe, sufficient, and satisfactory water supply.

The Director of Base Medical Services (DBMS) is responsible for conducting investigations to determine the suitability of water supply from the standpoint of health preservation and recommending any remedial action indicated. This requires periodic inspection of water sources, treatment measures, disinfection methods, water storage, and distribution, together with the routine collection and analysis of water samples and interpretation of results. Further, the Director of Base Medical Services is responsible for the review of proposed water supply projects and for determining whether necessary safeguards for potability have been incorporated.

Services of bioenvironmental engineers of the Medical Service should be used to evaluate the proposed water supply project.

Reports

Emergency situations related to water supplies, such as an outbreak of water-borne disease or the discovery of a major health hazard, are reported to major commands in a special Aerospace Medicine Report.

Discrepancies found through routine or periodic investigations of a water supply which may endanger potability, normally, are discussed in the recurring Aerospace Medicine Report. If no physical discrepancies exist, the statistical treatment of routine bacteriological water analyses, as set forth in AFM 160-4, serves to determine whether or not the supply meets minimum requirements of bacteriological quality during each reporting period.

Sources

Water for military supplies may be obtained from any of several types of water sources. Table 22-1 lists common sources and general considerations of their use:

Purchase of water from an approved public supply in a neighboring municipality is a widely used method of providing water for military installations. This is ordinarily the cheapest and best method when available, but may be limited in some oversea areas due to considerations of security, dependence, and public health standards.

When a choice of water sources is possible

Source:	Ground	Surface	Spring	Rain	Sea
Concerns:	Well Protection	Watershed Restrictions	Enclosure	Catchment Protection	....
Usual Treatment:	Aeration	Flocculation Sedimentation Filtration	....	....	Distillation
Safeguard:	Chlorination	Chlorination	Chlorination	Chlorination	Chlorination

in planning a military supply, ground water is preferable. Ground waters, normally, have better initial bacteriological quality and require less treatment than surface sources, thus reducing operational problems. In addition, the development of ground water is better suited to military considerations of security, decentralization, and protection against enemy action. However, development of ground-water resources under combat or field conditions is limited in view of requirements for well-drilling equipment and experienced hydrologists, and the time factor involved.

Sanitary surveys of established water sources are required at periodic intervals to insure that adequate protection exists for preventing the entrance of contamination into the supply. Where ground water is obtained through deep wells, the chief concern is that of preventing ingress of surface water through drainage or leakage into wells. With surface-water sources, the detection and elimination of gross contaminations, such as untreated sewage or industrial waste discharges, are the principal considerations.

Treatment

The most common treatment measures used with ground waters are the reduction of hardness and aeration. When large amounts of highly mineralized ground water must be used for industrial needs, such as for boiler water or laundries, softening of all or a part of the supply may be necessary. It is only rarely that ground-water supplies are so brackish that demineralization is necessary to make them satisfactory for consumption; consequently, Medical Service concern in this connection is limited. Removal or reduction of iron, manganese, hydrogen sulfide, and carbon dioxide, which are common objectionable constituents of ground waters, may be accomplished through aeration. Aside from being objectionable in water because of staining porcelain and laundry, imparting unpleasant taste and odor, or causing corrosiveness, presence of these substances above critical levels is of medical concern in attempting disinfection by chlorination. Significant amounts of dissolved iron, manganese, or hydrogen sulfide in water provide inorganic "chlorine demands" that give rise to difficulties in maintaining chlorine residuals. Dissolved carbon dioxide causes corrosiveness that will tend to pick up iron, copper, and lead from distribution lines as well as from service plumbing.

General treatment measures applicable to surface waters include storage, softening, coagulating, and filtration. Storage is frequently used to improve the physical characteristics of surface water through impoundment. Softening, as with some ground waters, may be necessitated for industrial usage. Purification of surface water is generally accomplished by complete treatment. This consists of coagulating the water through flocculation and sedimentation with subsequent filtration through rapid sand-gravity filters. This process mechanically removes the suspended material, varying amounts of tastes, odors and color, and practically all bacteria. Coagulation of water is performed by the addition of computed dosages of coagulant chemicals, followed by gentle agitation to permit the formation of gelatinous adhesive floc, after which a final period of quiescence is provided to allow the floc to precipitate and carry down suspended material. While the primary purpose of coagulation is to relieve filter loading so that long filtration cycles are obtained, it plays an important role in the removal of pathogenic microorganisms. Besides carrying down great numbers of microorganisms during the sedimentation phase, the fine particles of floc carried over to the filter beds form thereon an exceedingly fine bio-filter which effectively filters out virtually all remaining microorganisms. These additive benefits are lost when full surface-water treatment is reduced to rapid sand filtration only, as may be done to save chemicals during dry seasons when raw water turbidities are low.

In summary, Medical Service inspections of water-plant treatment measures should consider the purpose of the treatment employed and the effectiveness of these procedures. The latter is best indicated by appraising the completeness of laboratory control maintained and the technical competence of the operating personnel, provided design characteristics are suitable.

Disinfection

It is a military maxim that all water is to be regarded as contaminated until it has been disinfected. Chlorine is used by the military establishment as the disinfectant of choice for sizeable military water supplies. Because of the importance of proper disinfection of a water supply, Air Force regulations are very specific on this point and rigid requirements have been established. For these reasons, it is imperative that the Flight Surgeon maintain a continuous surveillance to insure that chlorination of the water supply is satisfactory at all times.

Water chlorination has a dual purpose: initial disinfection of the water, and protection of the supply during distribution by providing a chlorine residual to serve as a safety factor in the event of secondary contamination. The residual in the distribution system is generally not high enough to provide additional disinfection; however, the lack of a chlorine residual in the distribution system may be an indication of secondary contamination.

Chlorine is usually added to water as the final step of processing. It is introduced either through chlorinators as an aqueous solution of chlorine gas, or through hypochlorinators or solution feeders as a chlorine solution derived from the commoner hypochlorites. Free available chlorine (HOCl and/or OCl-ions) in water acts as a powerful, relatively quick-acting bactericidal agent. However, when ammonia or nitrogenous compounds are present in water, as is the case with many natural waters and, invariably, with waters which have been coagulated with ammonium alum, chlorine introduced initially reacts to form chloramines.

Chloramines are also bactericidal but have lower oxidizing potentials than free available chlorine; hence, chloramines must be employed in higher concentrations to equal the disinfectant action of free available chlorine. Differentiation of free available chlorine and chloramines in water is accomplished by the orthotolidine arsenite (O.T.A.) test described in "Standard Methods for the Examination of Water and Wastewater." (See References.)

As the bactericidal action of chlorine follows the slow rates of organic chemical reactions and is markedly influenced by factors of pH, temperature, and the form of chlorine present, disinfection is not completed for some time after chlorination. A minimum contact period of 30 minutes between chlorination and distribution to the first consumer is specified by regulation for Air Force-owned and operated water systems. This contact period must be provided for at finished water storage or distribution facilities.

At fixed installations, a measurable chlorine residual, after a 30-minute contact time, will be maintained at all times in the parts of the potable water distribution system under constant circulation. This does not apply to water directly supplied to installations, depots, leased buildings and similar facilities by a satisfactory public water supply distribution system that is approved by the appropriate State health authority. It does apply to military-owned and operated well and surface supplies and to water from municipal or privately owned systems where sanitary, physical, or operating defects and other special hazards are known to exist, or where bacteriological examinations show that satisfactory quality cannot be obtained without rechlorination by the installation.

Thus, for Air Force-owned and operated water supplies, the DBMS's concern with disinfection procedures consists of insuring the provision of an adequate contact period following chlorination, determining the types of chlorine residuals present, and maintaining a sufficiently close check by actual tests to insure that chlorine residuals carried in the active distribution system are satisfactory at all times. This involves the accomplishment of daily chlorine residual tests.

Fluoridation

Fluoridation of Air Force water supplies is becoming common practice. The safe concentration of fluorides in natural waters has been established as 1.5 ppm (parts per million) as set forth in AFM 160–4; concentrations of less than 1.0 ppm are the maximum ordinarily authorized when fluorides are added to water supplies to reduce the incidence of dental caries.

Justification for fluoridation of Air Force water supplies requires careful consideration and cooperation of personnel of the Dental Service and the Aerospace Medicine Service.

The Chief of Dental Services compiles information justifying the use of fluorides in the water supply in terms of the benefits received from fluoridation, the population using the water, and especially the number of minor children served.

The Bioenvironmental Engineer is concerned with accomplishing a complete field investigation of the water supply, type of proposed fluoride-feed mechanism, laboratory control tests, water plant safety regarding handling of fluorides, and economics of the process. Fluoridation of water supplies at Air Force bases should be coordinated with and approved by the Office of the Surgeon General per AFR 161–9.

The Aerospace Medicine Service is responsible for the routine determination of the fluoride residual. The fluoride content should be determined at least as often as the chlorine residual throughout the water distribution system. The method of determining fluoride concentrations may be found in "Standard Methods for the Examination of Water and Wastewater." (See References.)

Storage

Periodic inspections of water supplies should include appraisal of capacity of storage facilities with regard to the contact periods following chlorination. Protection afforded finished water while in storage is likewise important. Storage and distribution tanks should provide adequate protection against dust-borne or other accidental contaminations.

Distribution

Cross-connections constitute major hazards in water distribution systems. A cross-connection is a physical arrangement between a drinking-water supply system and a nonpotable system whereby flow into the drinking-water system is possible. Where dual systems exist for fire protection or industrial usages, consideration must be given to the possibility of such connections existing. Incomplete physical separation between the contents of swimming pools and their supply lines is another type. Faulty plumbing arrangements, such as leaking flush valves and their bypasses, are cross-connections and may cause back-siphonage of toiletbowl contents when partial vacuum conditions exist. Back-siphonage may occur on the uppermost fixtures in buildings when pipe sizes are too small to satisfy simultaneous water demands and when lavatories, sinks and other fixtures have under-the-rim inlets.

Cross-connections are seldom alike; some are in conjunction with equalizing tanks; others are direct connections to different supplies; often they are buried in boiler rooms, or are scattered in buildings over the area served.

Secondary contamination may also gain entrance into distribution systems through leaking joints or fractures, especially when sewer and water lines are in proximity and water tables are high or storm waters percolate around the lines. The greatest hazards of this nature are associated with antiquated distribution systems or military systems constructed from invasion-type materials that have exceeded their useful life.

Maintenance of constant positive pressure throughout a distribution system is of paramount importance against dangers associated with cross-connections and leaks. The occasional military expedient of conserving water in overtaxed supplies by valving off distribution systems or parts thereof is fraught with danger when underground lines are involved. Conservation should stress reduced usage.

Before placing new distribution systems in service, sterilization of all lines with heavily chlorinated water (50-100 ppm chlorine) for 24 hours is essential. This is also an established practice for new extensions to a system and for portions affected following main breaks and replacements or other major repairs.

Testing

Reliance for insuring the continuous potability of Air Force water supplies is placed largely upon the routine tests for chlorine residuals and bacteriological quality. The Director of Base Medical Services is charged with accomplishing these examinations in specified frequency and manner and interpreting the bacteriological findings. Since so much weight is attached to these indicative tests, it follows that every factor affecting their validity must be carefully appraised and appreciated by personnel to whom these responsibilities are delegated.

As the water samples tested are but a minute percentage of the total supply, it is essential that they be as representative of the total supply as possible. Sampling points for routine examinations should be selected by reference to a blueprint of the distribution system. They must be on active portions of the system, preferably from taps having the shortest run of service line from the mains. The number of sampling points chosen should correspond with the number of bacteriological samples to be examined each month and should be so placed over the system as to reflect principal usages. To obtain statistical validity, routine sampling points must remain fixed, with the same points used over each successive monthly testing cycle.

Bacteriological analyses of drinking water are based upon the demonstration of the presence or absence of the coliform group of organisms. Positive returns are only suggestive of the presence of the various waterborne pathogens. For this reason, interpretation of the significance of the analyses is a responsibility of the medical officer submitting the samples, rather than a laboratory responsibility, since the sum total of knowledge arrived at through sanitary surveys, inspections, and tests is necessary for proper evaluation.

The statistical treatment of routine bacteriological water analyses covered in AFM 160-4 is predicated upon establishing the bacteriological quality of the water supply as distributed. This limits consideration to samples taken from one supply and of that supply from the distribution system alone. Samples from raw water sources, treatment stages, off-base locations, other supplies, and those no longer representative of the water in distribution, such as samples from water jugs, mixing faucets, and the like, are of informational value only and are not to be included in the supply evaluation.

Field Supplies

The water purification equipment set, diatomite, portable 50 gpm capacity, is the standard Air Force water plant for producing potable water under field conditions at advanced air bases and temporary installations. The unit is readily transportable by cargo truck or aircraft, can be set up and placed in operation within 8 hours, and is capable of producing up to 60,000 gallons per day of clear, palatable water from any available surface-water source. This equipment was expressly developed to provide a method of field water production which could absolutely guarantee the removal of amebic cysts and schistosome cercariae from raw surface water sources. It became generally available toward the close of World War II and was used in Asia and the Pacific area. Since introduction, it has superseded previous types of field water-purification equipment employing sand-pressure filters, which could not be dependent upon to remove amebic cysts. Diatomite equipment was invaluable during the Korean campaign. (See figures 22-1 through 22-4.)

The principle of diatomite filtration consists of forcing raw water through a thin layer of diatomaceous silica (kieselguhr) plastered over supporting wire septa. Filtration achieved is equivalent to that provided by a laboratory Berkefeld filter. The filtrate produced is exceptionally clear, with more

(L to R) Finished Water Tank; Settling Water Tank; Coagulation Water Tank.

Figure 22-1. Field Water Purification Unit—50 GPM (3,000 Gallon Treatment and Holding Tanks).

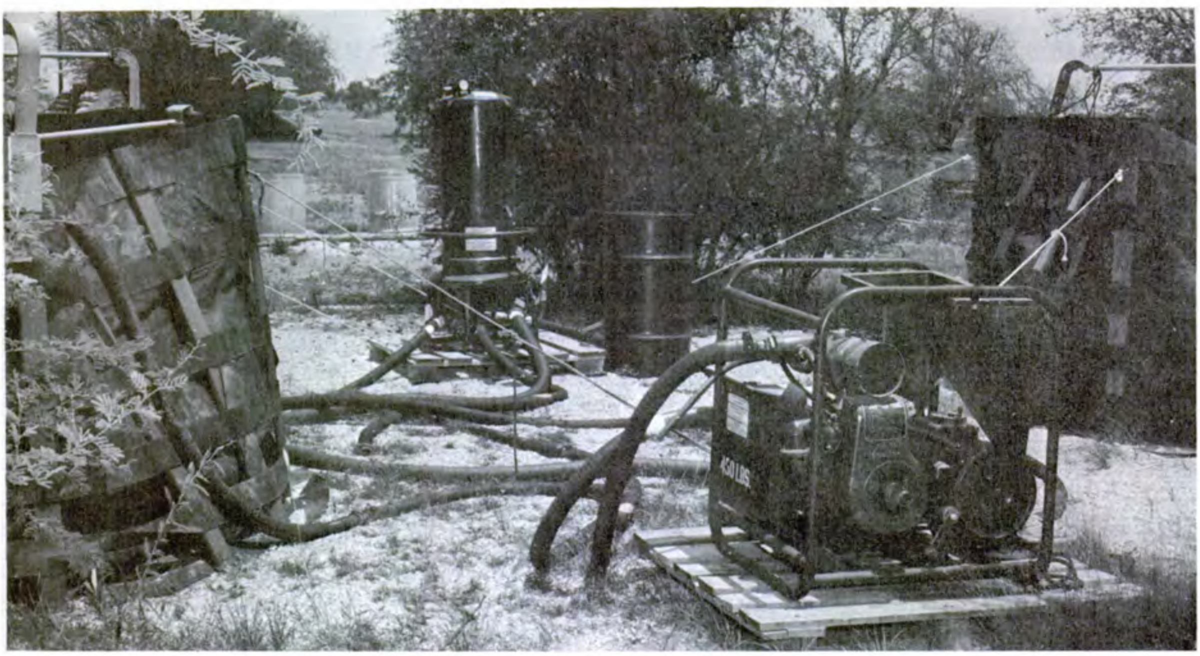


Figure 22-2. Field Water Purification Unit—50 GPM (Water Storage and Treatment Tanks; Diatomaceous Earth Filter Unit; Gasoline-operated Water Pump).

(Left to Right: Basic Septum Core; Septum partially wound; Septum as used in filter.)

Figure 22-3. Diatomaceous Earth Filter Septums.

Figure 22-4. Diatomaceous Earth Filter Unit With Precoating, Influent and Effluent Lines.

bacteria filtered out than is possible with conventional sand filters. Amebic cysts and schistosome cercariae, being comparatively large in relation to bacteria, are readily removed during this filtration process. Pathogenic bacteria remaining in the filtrate are destroyed by subsequent chlorination. With this equipment, the danger of amebic cysts surviving normal chlorine dosages is obviated through physical removal.

As with fixed military supplies, field diatomite water-purification equipment is operated by civil engineering personnel. Due to technical operating details and the advisability of coagulating and settling raw surface water prior to filtration, trained operators are of cardinal importance.

In field situations, diatomite water-purification units are usually some distance removed from the airstrip or quartering areas. Rarely is a river, stream, canal, pond, or other source of surface water immediately adjacent to the points of water usage. Distribution from the water point normally becomes a matter of each squadron or unit hauling water as needed in its own water trailers, five-gallon water cans, or other convenient receptacles. This kind of potable water distribution necessitates the closest surveillance to insure that secondary contaminations are not incurred. Disinfection practices for trailers or other containers prior to placing them in routine use, water-handling methods, exposure to dust-borne contaminations while in transit, and rechecking of chlorine residuals before the water is made available to consumers, should be usual concerns under these conditions.

The water purification equipment set, diatomite, pack (man), 15 gpm capacity, is also available through supply channels. This is a smaller unit designed to provide potable water in the field for small, isolated units. Principles of operation and considerations regarding water safety are the same as for the larger 50 gpm equipment set.

Distillation units of various types and capacities have been developed for the production of drinking-water supplies from sea water and brackish water. These units have been widely used on small islands and coral atolls in the Pacific where fresh water is not available. The distillate produced by equipment of this type must be protected by disinfection to prevent contamination by subsequent handling.

In field situations, residual chlorine concentrations of 1.0 ppm or more are required.

The establishment of adequate, safe and potable water supplies in field situations, to include bare base and/or forward areas, is the joint responsibility of the Air Force Civil Engineer and the Medical Service. Close liaison and coordination are essential between these personnel.

Emergency Purification

Under field or survival conditions, situations may arise that will require persons or small units to produce their own drinking water from raw sources or unsafe supplies. Certain items of water-treatment equipment and purification supplies are issued for these purposes. Their use, however, should be regarded as an emergency requirement, and water so processed should never supplant water obtainable from military supplies when the latter is available.

The water-purification unit, hand-operated, knapsack pack, filter pad type, ¼ gpm, was designed to provide small isolated units with a means of producing potable water. This unit consists of a small hand-operated diaphragm pump, double-faced filter disc, clamping ring, canvas carrying-case, paper filter pads, and accessories. It is issued as Water Purification Set No. 1, Knapsack Pack, ¼ gpm. The unit is simple, durable, and lightweight and can produce water of high clarity from turbid raw water. It will remove amebic cysts and schistosome cercariae from the raw water. Disinfection of the filtered water with water-purification tablets is necessary.

Small-scale units for obtaining drinking water from sea water are Air Force stock items used in life rafts and survival equipment. The type MK2 Sea Water Desalting Kit reduces the salt concentration of sea water to tolerable limits through chemical precipitation. The type LL2 Sea Water Distillation Kit accomplishes salt removal by utilizing solar heat on a plastic still.

Disinfection of untreated raw water may be necessary in emergencies. For small groups, the 36-gallon canvas Lyster bag carried in unit supplies for drinking-water storage and dispensing, can be used as a container for disinfecting raw water. The bag is filled to the mark with the clearest raw water available and an ampule of calcium hypochlorite broken and the contents added. After stirring, a 30-minute contact period must be observed before the water is consumed. Two ampules should be used when the water contains organic materials or when the presence of amebic cysts or schistosome cercariae in the raw water is of concern.

On an individual basis in emergencies, water may be disinfected in a canteen with water-purification tablets. These are available as Tablets, Water Purification, Individual, Iodine, containing tetraglycine hydroperiodide ("Globaline") as the active ingredient. The tablets should be used according to the instructions on the vial. *The "Halazone" individual water purification tablets are obsolete and should not be used.*

Under extreme emergency conditions, raw water may be rendered safe by boiling for at least 15 minutes. Quantities required for drinking should be prepared as needed due to the danger of secondary contamination occurring without the safeguard provided by chlorine residuals.

REFERENCES

The reader should insure the currency of listed references.

AFM 88–54, *Air Force Civil Engineer Handbook.*

AFM 160–4, *Sanitary Control of Water Supplies for Fixed Installations.*

AFM 160–25, *Engineering Data, Preventive Medicine and Occupational Health Program.*

AFR 91–10, *Water Works.*

AFR 161–9, *Fluoridation and Defluoridation of Water Supplies.*

AFR 161-14, *Swimming Pools.*

TB MED 190, *Water Treatment in Areas Where Amebiasis and Schistosomiasis Are Hazards.*

TO OO 105C-3, *Ground Water Supply for Military Operations.*

TO OO 105C-4, *Military Water Supply and Purification.*

TO OO 105C-6, *Operation of Water Supply and Treatment Facilities at Fixed Army Installations.*

Public Health Service Drinking Water Standards (1962).

Standard Methods for the Examination of Water, and Wastewater, 11th Edition, American Public Health Association, 1790 Broadway, New York, NY (1960).

Chapter 23

CONTROL OF ARTHROPODS AND RODENTS OF MEDICAL IMPORTANCE

Responsibility

The responsibility for arthropod and rodent control is divided between the Medical Services and the Civil Engineering Services. AFRs 161-1 and 91-21 define these responsibilities. In general, the Base Civil Engineer plans, initiates and supervises arthropod and rodent control activities, whereas the Director of Base Medical Services has primarily survey and advisory responsibilities. The Medical Service responsibilities may be listed briefly as follows:

a. To watch closely over adjacent communities to detect vector-borne diseases.

b. To make frequent periodic on-base surveys to determine the presence of vectors of arthropod or rodent-borne diseases, or of pest species.

c. To recommend to the Base Civil Engineer that appropriate control programs be initiated when surveys demonstrate the presence of disease vectors or of pest species adversely affecting morale.

d. To furnish advice on control measures and chemicals to be used.

e. To monitor the effectiveness of control programs for vectors and pest species.

f. To assist in instructing vector control personnel concerning toxicity, safe handling and application of insecticides.

g. To assist in instructing all military personnel regarding personal protective measures.

Surveys

Thorough field surveys must be made to determine the presence of disease vectors or pest species, and, if present, whether the populations of these species are large enough to warrant area-wide control programs. The initial base survey is best made by an entomologist trained in survey methods and the identification of vector and pest species. Consultant services for the initial survey in the CONUS and Alaska should be requested from the USAF Epidemiological Laboratory (see AFR 161-21) or in oversea areas, from the 4th Epidemiological Flight in USAFE or the 5th Epidemiological Flight in PACAF (see AFR 161-12).

Periodic and continuing surveys and monitoring of the efficiency of routine control programs should be made by the Director of Base Medical Services in accordance with procedures recommended by the medical entomologist during his initial base survey. AFM 85-7 contains a brief summary of survey methods. Surveys should be continued at weekly intervals during the warm months, or throughout the year in tropical areas.

Identification

Successful control programs can be planned only when the vectors and pests have been accurately identified, and when information is available on their life history, breeding sites and bionomics.

Identification requires technically trained personnel who are not available at the average Air Force hospital. Specimens for identification should be sent to the USAF Epidemiological Laboratory, to the 4th or 5th Epidemiological Flights, or to the nearest Army Area Medical Laboratory per AFR 160-62. Information on life history and bionomics will usually be available from medical entomologists, but delineation of the breeding areas will have to be made at the base level.

In general, adult mosquitoes and other flies of medical importance should be submitted for identification in pill boxes between layers of kleenex or toilet paper. Most other medically important arthropods and larvae of mosquitoes and flies should be preserved and shipped in 70% grain alcohol in vials. Adequate data as to locality and date of capture should be included with each sample sent for identification. Specimens should be preserved and mailed in accordance with "Collection and Preservation of Insects," Misc Publ 601, US Department of Agriculture. Free copies are available from that agency upon request.

Control

The two general types of arthropod and rodent control measures employed in the Air Force are physical and chemical.

a. Physical control measures are often more expensive initially, involve more personnel and require more planning. Physical measures are aimed at removal or denial of breeding areas, harborage and food. They are more effective than chemical controls, and are less costly in the long run.

b. Chemical control measures are temporary in nature, and although they can be carried out quickly by a minimum of personnel, they are less effective than permanent physical control methods, and more expensive over a long period. Chemical measures are usually easier to carry out while the insects are in one of the young stages. Many arthropod eggs are laid in batches in small areas and the young are thus concentrated. Such concentration makes it easier and cheaper to kill large numbers of arthropods with less insecticide and labor than if the adults are attacked later. Some, however, are not accessible until they are full grown, and must be controlled by direct attack of the adults.

c. If control by chemical means is selected, the utmost care must be exercised to insure that only approved insecticides are used, that insecticides are employed safely and at the recommended dosages. If properly applied at the recommended rates, the chance of damage to wildlife is minimized.

d. Recommended insecticides and dosages are subject to frequent changes as new compounds are made available or as resistance is developed by insect species. The Communicable Disease Center, USPHS, Savannah GA 31401, publishes a useful annual report, "Public Health Pesticides," copies of which are available from that agency. The Armed Forces Pest Control Board issues periodic revisions of Technical Information Memorandum No. 6, "Current Pest Control Recommendations." The Disease Vector Control Centers (DVCC), US Navy, periodically revise "Recommendations for Chemical Control of Disease Vectors and Economic Pests."

The US Public Health Service (USPHS) and DVCC publications on vector control list both standard and nonstandard pesticides. Air Force users are cautioned to requisition and apply only pesticides listed in Military Supply Standard, Class 6840.

General

a. In order to avoid classification problems, ticks, mites, and some venomous arthropods are included under the term "insects"; although they are not true insects at all.

b. The insects may be divided into two general groups; beneficial and harmful.

(1) The beneficial insects include scavengers which rid us of organic waste material; the parasites and predators which help in the fight against harmful insects; and the pollinators. These groups are so important economically that great care must be taken to avoid their destruction in any large control operations.

(2) The harmful insects fall into three groups: economic, pest, and medical.

(a) Economically harmful insects include those which destroy crops, forests, food and clothing, and which affect the health of cattle and pets. The control of these insects is of minor importance on a military base, such work frequently being the responsibility of federal and local departments of agriculture.

(b) Many pest insects have no particular economic or health importance to man, but are a great nuisance, and may affect morale.

(c) There are many insects involved in the transmission of diseases to man, mosquitoes being the most widely known group. Of 126 diseases communicable to man, 61 are entirely or partially insect-borne.

DISEASE VECTOR CONTROL

Mosquitoes

Diseases and Vectors:

Malaria—*Anopheles quadrimaculatus* and other Anopheles spp.

Yellow fever—*Aedes aegypti, Haemogogus* spp.

Dengue fever—*Aedes* spp.

Encephalitides—*Culex* and *Aedes* spp.

Filariasis—*Culex, Aedes, Mansonia* and *Anopheles* spp.

Breeding:

Eggs laid in or near water; the larvae ("wigglers") and pupae ("tumblers") are aquatic; may be found in ponds, puddles, streams, marshes, tree-holes, cow-hoof holes and artificial containers such as tin cans, old tire casings, flower vases and gutters.

Control:

Physical. Draining of water; filling ponds and other breeding areas with dirt; removal of artificial breeding areas; ditching of swamp and marsh areas; screening of buildings.

Chemical:

Adults:

Indoors. Space spray with synergized allethrin aerosol at a rate of 7 seconds per 1000 cubic feet. Residual spray with 2.5 to 5% DDT at 1.0 gallon per 1000 square feet; if resistance has developed to this chlorinated hydrocarbon insecticide, use 2 to 5% malathion at 1.0 gallon per 1000 square feet. Residual sprays are applied to the point of runoff.

Outdoors. Apply 5 to 10% DDT or 6% malathion oil solutions at a rate of 40 gallons per hour at 5 mph as a fog or mist, or 5% malathion dust at a rate of 6 lbs per acre; this affords temporary relief only.

Larvae:

Ground Applications. 1.0% emulsions or oil solutions of chlordane or dieldrin at a rate of 0.1 lbs of toxicant per acre or of DDT at a rate of 0.2 lbs of toxicant per acre; where resistance to chlorinated hydrocarbons has developed, malathion oil solution or granules may be used at a rate of 0.2 lbs of active ingredient per acre (0.5 lbs may be used in nondraining areas where there is no hazard to wildlife).

Aerial Spraying. Applications are made by the Special Aerial Spray Flight (SASF), HQ TAC; requests should be processed per AFR 91-22; aerial spraying should be done only when effective control cannot be obtained by conventional ground applications.

Personal Protection. Use of skin or clothing repellents; head nets may be used in areas where heavy concentrations of pest species are present; mosquito bars should be used by personnel sleeping outdoors or in unscreened buildings.

Flies

Diseases and Vectors:

Typhoid fever—*Musca domestica* (housefly) and others.

Cholera—*M. domestica* and others.

Dysenteries and diarrheas— *M. domestica* and others.

Tularemia—*Chrysops discalis* (deer fly).

Leishmaniasis—*Phlebotomus* spp. (sand fly).

Trypanosomiasis—Tsetse fly.

Fly-borne diseases may be transmitted by mechanical means, as are the intestinal diseases and tularemia. Others are transmitted only after completion of part of their life cycle in the fly, as is trypanosomiasis.

Breeding:

Houseflies and other "filth-flies"; in manure, garbage, spillage and other organic material. Other flies: varied; the deer fly breeds in soil at the edge of streams; the true sand flies in cracks and crevices, and in rock walls. The breeding habits of flies are so varied that the life history of the individual

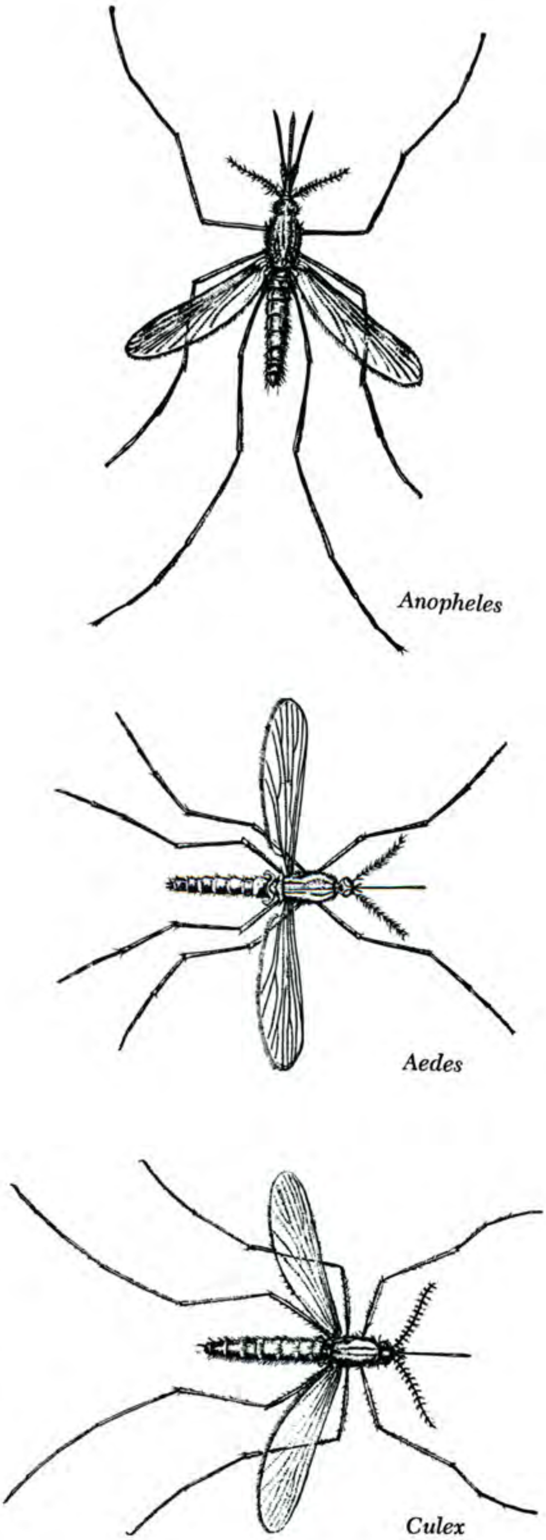


Figure 23–1. Mosquitoes.

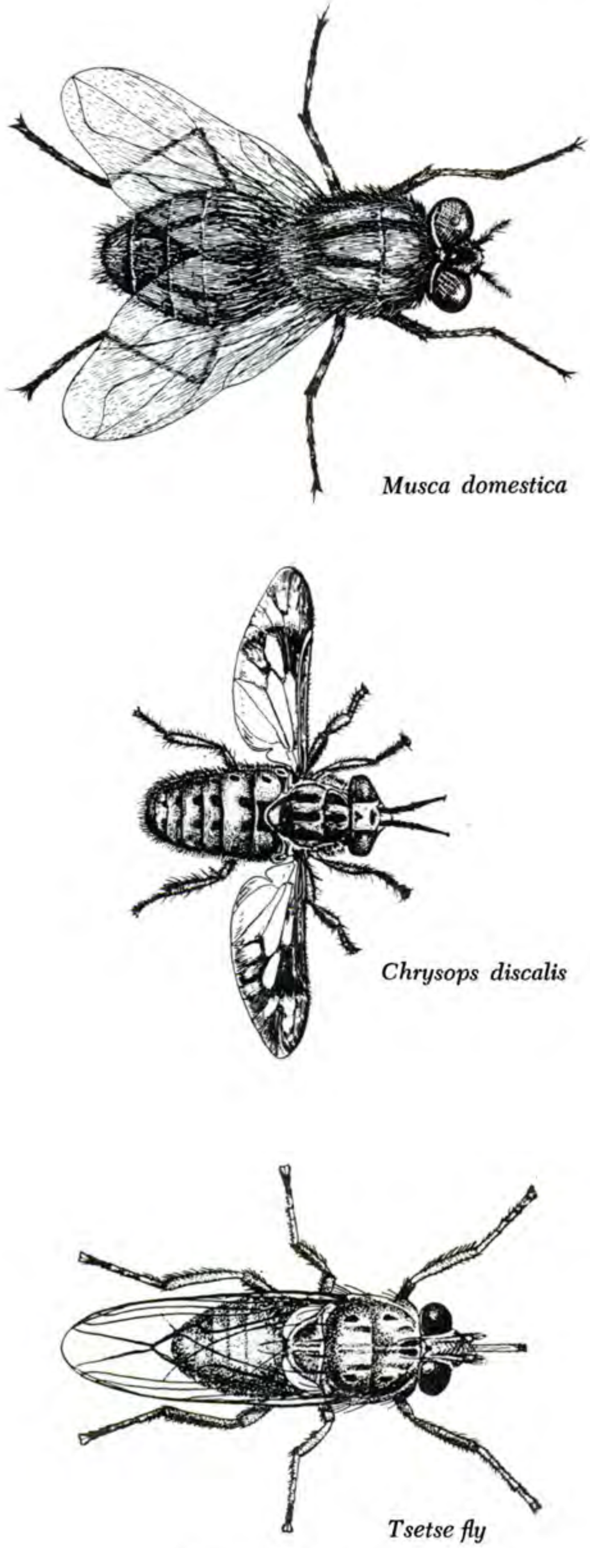


Figure 23–2. Flies.

species must be known for permanent control.

Control:

The nearly universal resistance of houseflies and blowflies to chlorinated hydrocarbons, and the rapidly developing resistance to organic phosphate insecticides reemphasizes the necessity for good sanitation in fly control.

Physical. The proper operation of incinerator or sanitary fill for garbage disposal; proper handling of garbage at messhalls; proper sewage disposal; and screening of buildings.

Chemical:

Indoors. As a residual treatment use an oil emulsion containing 1.0% diazinon or 5.0% malathion applied as a spot treatment to the point of runoff (1 gallon per 1000 square feet).

Outdoors. Baits for use outside messhalls may be prepared from 1 fluid ounce of 47.5% emulsifiable diazinon plus 3 lbs sugar in 3 gallons of water, or 2 lbs of 25% malathion wettable powder plus 23 lbs sugar. Space sprays may be used at rate of 5 gallons 57% malathion emulsifiable concentrate in 41 gallons water at a rate of 20 gallons per mile or 6 gallons 47.5% diazinon emulsifiable concentrate in 39 gallons water at a rate of 15 gallons per mile. Residual sprays may be used on inner walls of pit-type latrines, but pit contents should not be treated since this eliminates breeding of desirable scavenger species.

Fleas

Diseases and Vectors:

Bubonic plague—*Xenopsylla cheopsis* (Indian rat flea) and others.

Murine (endemic) typhus—*Xenopsylla cheopsis.*

Sylvatic plague—Many species from wild rodents.

Breeding:

Eggs are laid in the nest or bed of the host, or in the host's fur or feathers. In the latter case, they usually fall to the ground or to the nest. The larvae are very active, crawling around the nest or bedding material, or on rugs, on the floor, or on the ground.

Control:

On host animals. Dust dogs and cats with 5% malathion or 0.2% synergized pyrethrum dust; 1% lindane and 2 to 4% chlordane dusts may be used on dogs *only.*

Treat bedding and resting places of pets at same time. Infestations in buildings may be controlled by 1% malathion spray or 4 to 5% malathion dust. In yards, treat ground with 1% diazinon or 2% malathion emulsion at 1 gallon per 1000 square feet, or 4 to 5% malathion dust at 1 to 2 lbs per 1000 square feet.

Lice

Diseases and Vectors:

Epidemic typhus fever—*Pediculus humanus.*

Relapsing fever—*Pediculus humanus.*

Dermatitis—*Phthirius pubis* (crab louse) and *Pediculus humanus.*

Breeding:

Body louse. This subspecies of *Pediculus humanus* breeds, lives and lays eggs primarily in the seams of the clothing.

Head louse. This subspecies mainly inhabits the head hair and head gear, the eggs, or nits being laid on the hair.

Crab louse. Found primarily in pubic region, but may spread to hair of chest and axilla, and even to the head. Occasionally found on toilet seats or bedding. This species seldom goes to the clothing, but remains attached to the body hair.

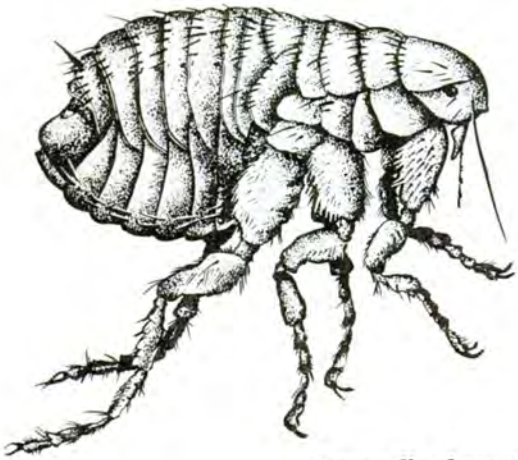
Control:

Ten percent DDT or 1% lindane dusts may be applied to body parts and to clothing; where resistance to chlorinated hydrocarbons is encountered, a 1% malathion dust is recommended. Good personal hygiene, including frequent baths and laundering of clothing, is imperative. Personnel should not bathe for 8 hours after treatment with insecticide.

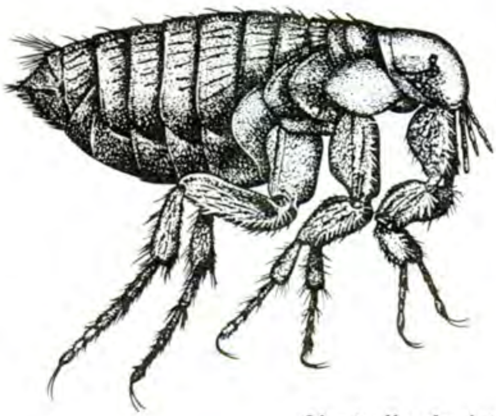
Ticks (Not Insects)

Diseases and Vectors:

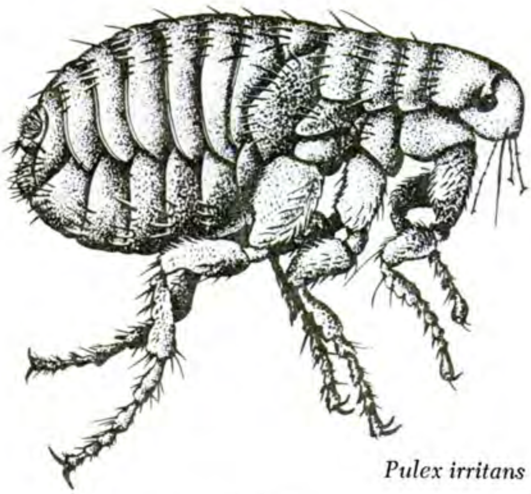
Tularemia—*Dermacentor andersoni, D. variabilis, Amblyomma americanum,* others.



Xenopsylla cheopsis



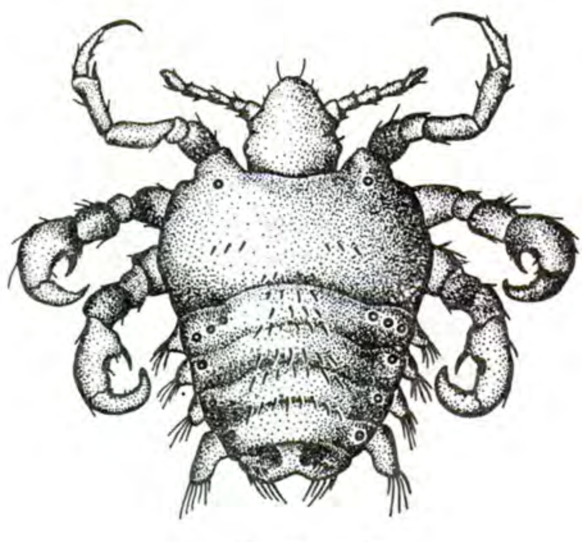
Nosopsyllus fasciatus



Pulex irritans

Figure 23–3. Fleas.

Pediculus humanus



Phthirius pubis

Figure 23–4. Lice.

Relapsing fever—*Ornithodorus* spp.; others.

Encephalitides—*Dermacentor* spp. and *Ixodes* spp.

Rocky Mountain spotted fever—*Dermacentor andersoni, D. variabilis, Amblyomma americanum;* others.

"Q" fever—*Dermacentor andersoni, D. occidentalis, Haemaphysalis humerosa,* others.

Tick paralysis—*Dermacentor andersoni, D. variabilis.*

Breeding:

Ticks are ectoparasites, feeding on various animals. After each feeding they drop off and molt, then await a new host. Some species feed only once a year and require a different kind of animal host for each feeding. The species that attack man are usually found in grassy or wooded areas. These species climb up the outside of the clothing and usually attach on the back of the neck.

Control:

Personal. Skin (diethyltoluamide) and clothing (M1960) repellents; personal body inspection and removal of attached ticks.

Animals. Dip or sponge pets in 0.5% lindane or 0.5% malathion solution, or dust with 4% malathion; lindane should not be used on cats.

Area. Spray or dust applications of DDT, chlordane, and dieldrin at 1 to 2 lbs active ingredient per acre or BHC at 0.5 lbs of gamma isomer per acre. Avoid treatment near streams at the higher concentrations because of toxicity to aquatic life.

Building. Spot treatment of infested areas with diazinon as a 0.5% emulsion or solution, or spray with 1 to 2% malathion at a rate of 1 to 2 gallons per 1000 square feet. Do *not* use diazinon on animals.

Mites (Not Insects)

Diseases and Vectors:

Scrub typhus—*Trombicula akamushi, T. deliensis.*

Rickettsial pox—*Allodermanyssus sanguineus.*

Endemic (murine) typhus fever—*Bdellonyssus bacoti.*

Scabies (7-year itch)—*Sarcoptes scabei.*

(Mites are also important pests of man—*i.e.,* "chiggers" or "redbugs," and various species of bird mites and rat mites that occasionally swarm in houses.)

Breeding:

The mites of medical importance to man are parasitic in at least one stage of their development. In general, they are found either on a host animal or in grass or other vegetation. Control is thus dependent upon the species involved. The mites that carry endemic typhus are found on rats or in the rats' habitat. The mites that serve as vectors of most other diseases are usually found on grass or on organic matter such as leaves, mold and dead logs.

Control:

Personal. Skin (diethyltoluamide) and clothing (M1960) repellents.

Area. Spray or dust treatments of chlordane (1 to 2 lbs per acre), lindane (0.25 to 0.5 lbs per acre) or dieldrin (0.6 to 1.0 lb per acre). Avoid treatment near streams at the higher concentrations because of toxicity to aquatic life.

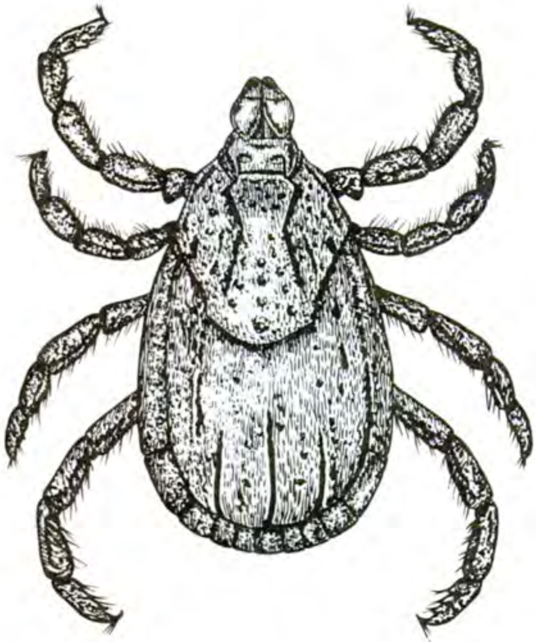
PEST INSECT CONTROL

The pest insects include those which do not carry disease. Many insect groups contain both disease-carrying and pest members. Such groups have already been covered in preceding sections if they are of importance as disease vectors.

Cockroaches

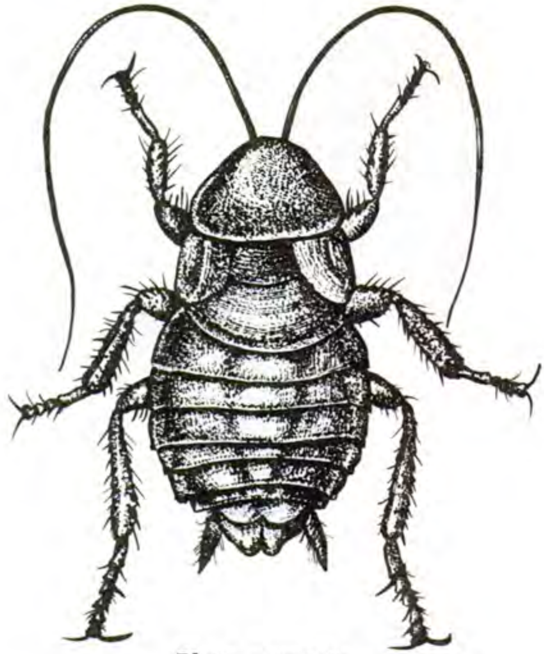
Breeding:

Cockroaches (*Periplaneta americana, Blattella germanica, Blatta orientalis, and others*) live in cracks and crevices in walls, cupboards, and around water pipes. Some species carry the egg sacs until hatching occurs while others glue the egg sacs to the underside of drawers and shelves. Roaches can travel easily within buildings, even those which are partitioned off into sections, and are often spread to new areas with groceries and other packages.

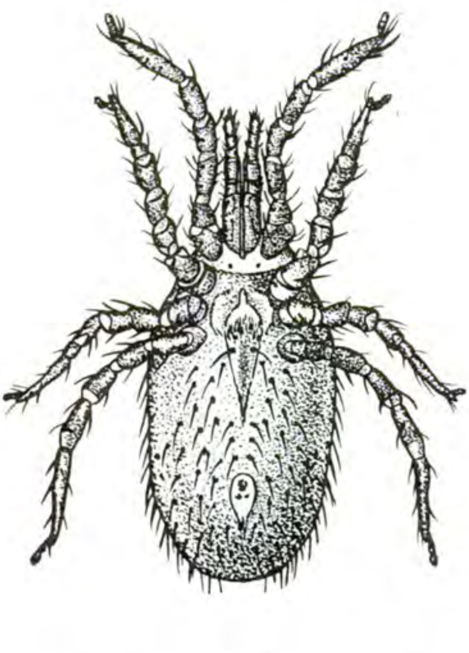


Dermacentor variabilis

Figure 23–5. Tick.

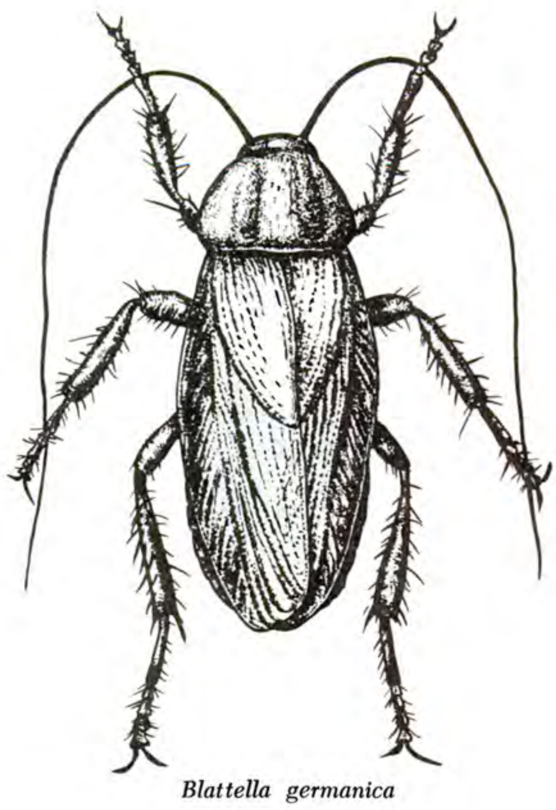


Blatta orientalis



Allodermanyssus sanguineus.

Figure 23–6. Mite.



Blattella germanica

Figure 23–7. Cockroaches.

Control:

Physical. Proper, tight construction of new buildings coupled with scrupulous cleanliness can virtually eliminate cockroaches.

Old buildings can be made somewhat "cockroach-proof" by sealing cracks, crevices and pipe holes with putty, woodfiller, plaster, or concrete.

Chemical. Insecticides for cockroach control should be applied as "spot-treatment," placing small amounts in cracks, corners, under cupboard drawers, behind refrigerators and in other hiding places.

Use coarse spray of 3% chlordane or 0.5% dieldrin as a spot treatment; 1% malathion spray for populations resistant to chlorinated hydrocarbons; or combination of 0.5% diazinon spray and 2% diazinon dust. Second application should be made about a month later; subsequent applications at 3-month intervals should control infestations satisfactorily.

Bedbugs

Breeding:

Bedbugs (Cimex lectularus) breed in cracks and crevices in walls, in beds, and in the spaces along the rolled edges of mattresses. They are frequently picked up on trains and buses, and in theaters and hotels. Bedbugs bite at night, and then retire to their hiding places. Often, the only sign of their visit is the presence of bites, or of tiny blood spots on the bedding.

Control:

5% DDT in colorless, odorless kerosene, sprayed on mattresses and beds, and in cracks and crevices on base boards, floors, and walls at a rate of 1 gallon per 1000 square feet. All rooms in the building should be sprayed unless the building is too large to make this practical; in this case, rooms in and near the infested area should be sprayed. 1% malathion at the same rate may be used if DDT proves ineffective. 0.5% lindane will give control if other chemicals fail, but should not be used on mattresses.

VENOMOUS ARTHROPOD CONTROL

Venomous arthropods are of importance because of their bite or sting, which may produce local symptoms or even death.

Black Widow Spiders—(Latrodectus mactans)

The black widow is the only spider in the United States whose bite is poisonous to man. Deaths occur mainly in males, who are bitten in the genital region, while using outdoor privies. Danger is also great among infants and the very aged.

Breeding:

Black widows breed in lumber piles, stumps, trash piles, undersides of privy seats, cracks and crevices in and under houses, and under old lumber, roofing material, cans and other pieces of trash on the ground.

Control:

Physical. The best control is through the cleaning-up of breeding areas. Trash should be disposed of only at dumps, where it can be covered or burned. Education of personnel should not be overlooked.

Chemicals. 5% chlordane dust is excellent for chemical control; oil sprays containing 2% chlordane, 0.5% lindane or 3% malathion may also be used. The insecticides should be applied to inner walls of privies and other breeding areas at regular intervals, the time to be determined by survey.

Scorpions—(Centruroides sculpturatus and others)

There are about 50 species of scorpions in the United States, but only one Arizona species is known to cause death in man. The toxin is carried in the stinger, being injected by a downward thrust of the tail.

Breeding:

Scorpions are usually found under stones, in decaying wood, and under trash piles, while some Southwestern species may hide in sand. They often invade houses and tents, hiding in dark corners, under furniture, and in shoes.

Control:

Education of personnel in the methods of avoiding contact offers the best means of combating scorpions.

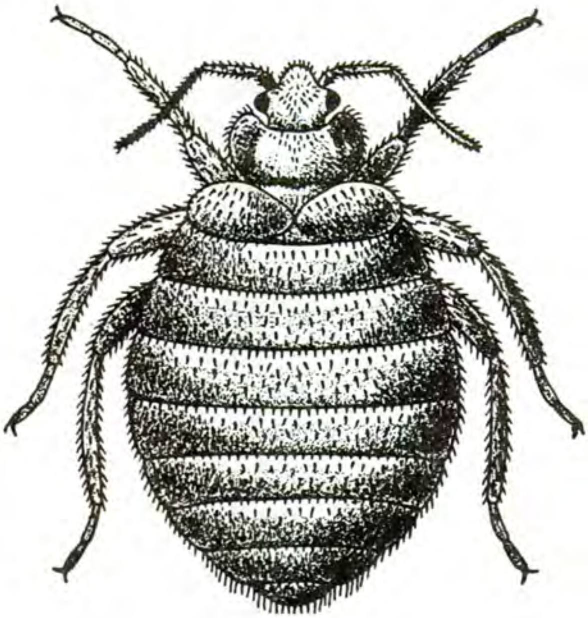


Figure 23-8. Bedbug.

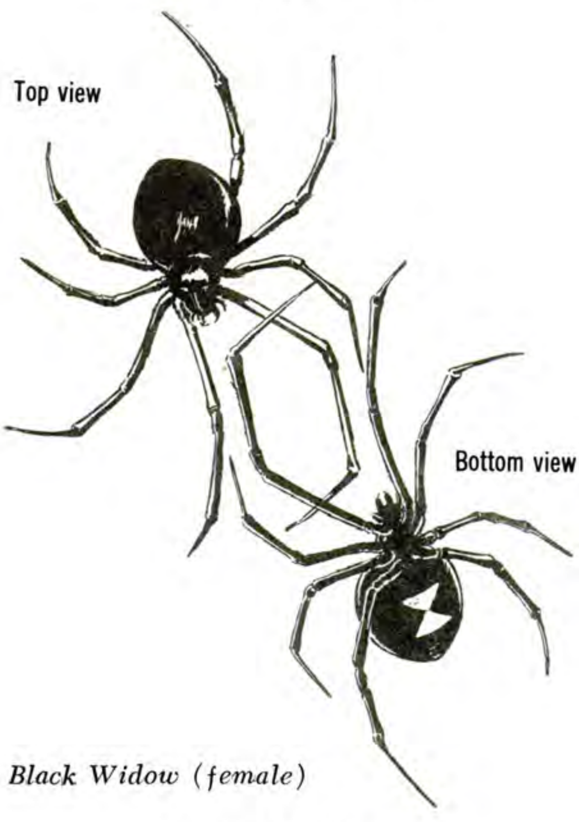


Figure 23-9. Spider.

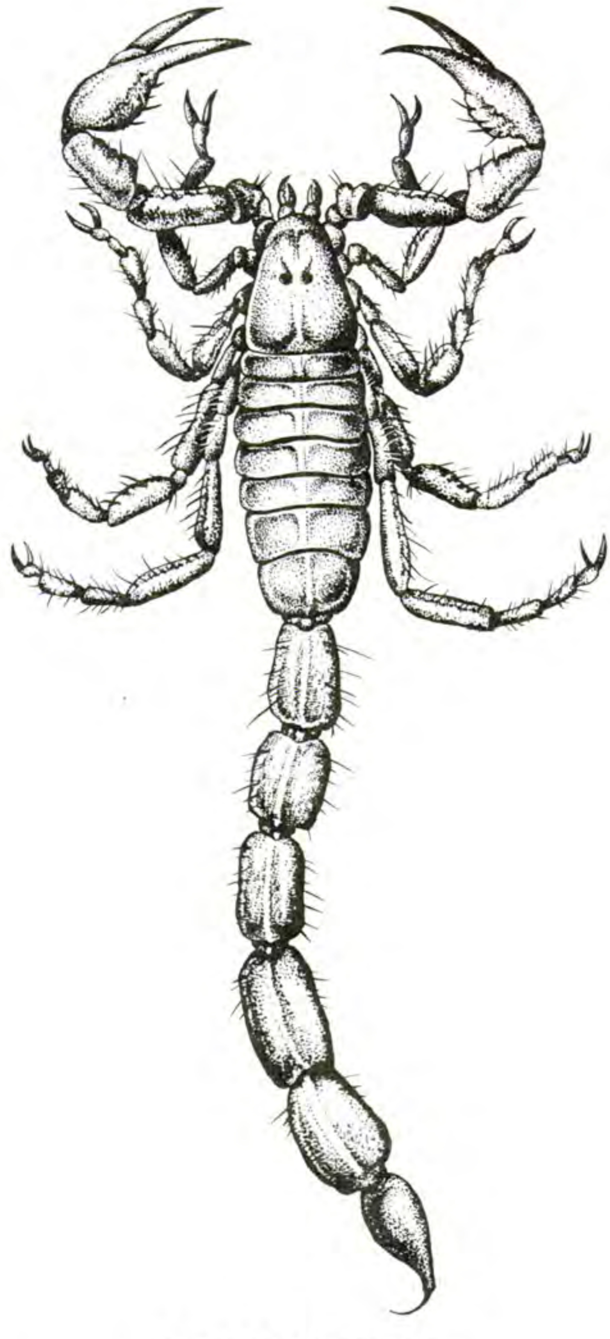


Figure 23-10. Scorpion.

Physical. Cleaning and clearing of possible hiding places.

Chemical. Indoors, spray with emulsion containing 2% chlordane or 0.5% dieldrin at a rate of 1 pint per 125 square feet; outdoors, use the same spray as required.

Wasps and Bees

There are many species of wasps and bees which can inflict painful stings. The venom sometimes produces severe systemic or allergic reactions that occasionally result in death through anaphylactic shock. The social wasps (hornets, yellow jackets and paper wasps) and social bees (honeybees and bumblebees) are particularly dangerous because they will attack in numbers if their nests are disturbed. Some solitary species whose stings have been reported as causing severe reactions are sweat bees, mud dauber wasps, velvet ants, and bethylid wasps. The solitary species are not aggressive in defense of their nests; ordinarily they will sting only when handled.

Breeding. Hornets build large paper multicombed nests in trees or bushes, or in the sidings of houses; yellow jackets build similar paper nests in the ground; and paper wasps build umbrella-shaped, single-combed nests in protected situations such as under porch roofs, house eaves, etc. Colonies of wild honeybees may nest in hollow trees or in sidings of houses. Bumblebee nests are usually found on or just below the ground surface, or, occasionally, in abandoned birds nests. The solitary wasps and bees are quite diverse in their nesting habits; some build clay cells in sheltered situations, some nest in borings in wood, and still others nest in the ground.

Control:

Physical. Mud-dauber nests may be knocked off the building where they are attached. It may be necessary to apply a residual spray to discourage further nesting at the site.

Chemical. Control procedures against social wasps and bees are best undertaken at night when the insects are not active. Colonies in underground nests and those in the siding of houses may be destroyed by fumigation with a nonflammable substance such as chloroform or carbon tetrachloride; half a cupful should be poured into the nest opening and then the opening should be plugged with earth or a tight plug of absorbent cotten; precautions should be taken so that personnel are not exposed to the fumes. Populations in aerial nests may be destroyed by directing a dust of 5 to 6% chlordane, 1% dieldrin or 5 to 10% DDT into and around the openings, or spray with a 2% chlordane, 5% DDT or 0.5% dieldrin oil solution; or, aerial nests may be dislodged, placed in a sack and buried or treated with fumigant in a garbage can. Aggregations of ground-nesting wasps and bees may be destroyed by spot treatment of the nest openings with a dust containing 5 to 10% DDT, 5 to 6% chlordane or 1% dieldrin. Occasionally, wasps may enter attics or cellars in large numbers in the fall to hibernate; they may be killed with the allethrin-DDT aerosol bomb.

Urticating Arthropods—(Various species)

There are a number of beetles and other arthropods which produce blisters if handled or touched. In addition, the caterpillars of various moths can produce a severe dermatitis upon contact.

Control:

Control measures depend on accurate identification. The local Health Department, or local Department of Agriculture can usually identify and recommend control measures for these pests.

Tarantulas—(Eurypelma spp.)

Tarantulas are large hairy spiders. They are widely feared, but are not poisonous to man, although they can inflict a painful bite.

Control:

Control of tarantulas is similar to that of spiders and scorpions.

Control of Other Insects

There are many other insects that may be of importance on air bases. Control measures for many of these can be found in AFM 85-7. Control of unknown insects must be based on identification of the insect by the USAF Epidemiological Laboratory, Epidemiological Flights, or the Army Area Medical Laboratory.

RODENTS

Rats are the rodents of primary importance in most areas. However, there are many Air Force installations in areas where mice and other rodents are the principal problem. Rodents, of course, are of great economic importance as destroyers of food and property, but their main interest to the Medical Service lies in their disease-carrying potentialities.

Rodents are involved in disease transmission in two ways: as primary disease vectors, and as hosts of ectoparasites that transmit diseases.

Diseases

a. Rodent transmitted:
- (1) By rat bite:
  - Haverhill fever—*Streptobacillus moniliformis.*
  - Rat bite fever—*Spirillum minus.*
- (2) By contamination of food and water:
  - (a) Contamination with urine:
    Weil's disease (leptospirosis)—*Leptospira, sp.*
  - (b) Contamination with feces:
    Salmonellosis—*Salmonella spp., Shigella* spp.

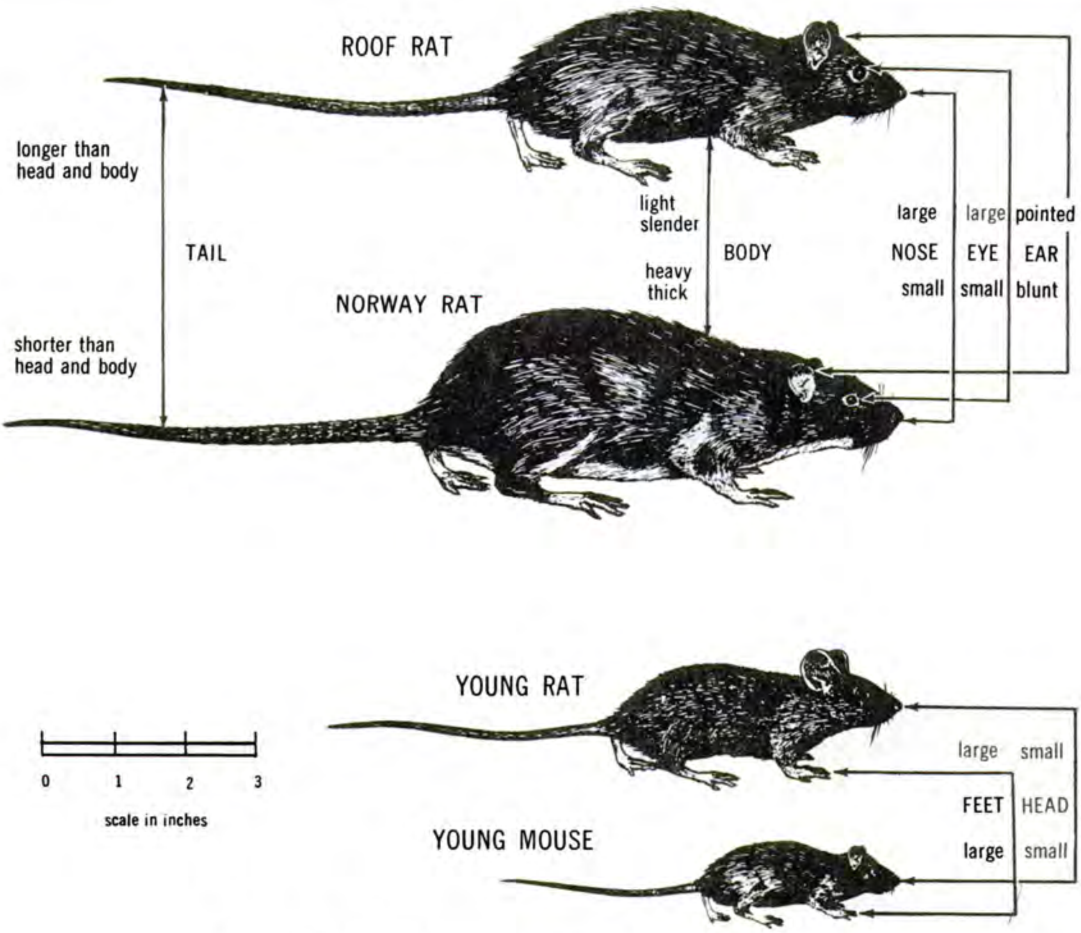


Figure 23–11. Field Identification of Domestic Rodents.

(3) By inhalation of mouse feces:
Lymphocytic choriomeningitis

b. Rodent ectoparasite transmitted:

(1) By fleas:
Plague.
Endemic (Murine) typhus

(2) By mites:
Endemic (Murine) typhus (exp.)
Scrub typhus
Rickettsialpox
Epidemic hemorrhagic fever

(3) By ticks:
Tularemia
Rocky Mountain spotted fever
"Q" fever
Relapsing fever
Russian spring-summer encephalitis

Control:

Physical. The most important, and most effective rodent control measures involve denial of harborage food and water. Such measures include ratproofing of buildings and proper storage of foodstuffs.

Destructive. Trapping is a good method of rodent control, but is secondary in effectiveness to poisoning, to which it is often used as a supplement.

Chemical. Anticoagulant compounds are the poisons of choice for rodent control. They are slow acting and have a low degree of toxicity to humans and pets. Three commonly used anticoagulants are fumarin, pival and warfarin. They should be used at a concentration of 0.025% active ingredient by weight in solid baits. Diphacinone is used at a concentration of 0.005% active ingredient by weight, and PMP at 0.05% active ingredient by weight.

Liquid (water) baits may be more effective than solid baits where water is scarce or a variety of foods are available. The sodium salts of warfarin, pival and fumarin are used at a strength of 0.006% acid equivalent and PMP at 0.015%; 5% sugar should be added as an attractant.

Zinc phosphide is used as an alternative poison in solid baits at a rate of 1/5 oz per 1 lb of food. It should be mixed outside and set out in areas protected from moisture.

Note: Sodium monofluoracetate, "1080," is extremely toxic and should be used only under emergency (plague) situations with the approval of the Surgeon General. (AFM 85–7 reserves approval for use of 1080 to Surgeons General.)

Rodent burrows outdoors may be fumigated with calcium cyanide dust.

Runways should be dusted with a 4 to 5% malathion, 1% lindane, or 2 to 4% chlordane dust before a rodent control campaign is begun in a plague epidemic, so that infected fleas will be destroyed before they leave the dead rats and attack man.

FORMULAS FOR MIXING PESTICIDES

Most pesticides are now received in concentrated form to save shipping bulk and cost. It is therefore necessary to mix most of these chemicals to the desired strength. Two formulas for mixing are given below; others may be found in AFM 85–7.

a. Weight-volume formula:

This formula is used for mixing liquid and dry materials.

Multiply together:

Gallons of spray wanted *times* weight of one gallon of diluent *times* percent of active ingredient wanted.

Divide:

The result of the above multiplication by the percent of active ingredient in the concentrate ("Technical Grade" is usually 100%).

Equals:

Pounds of concentrated pesticide to be added.

Example:

Make 25 gallons of 2% chlordane, using 100% chlordane dust and kerosene (wt 6.6 lbs/gal).

$$\frac{25 \times 6.6 \times 2}{100} = 3.3 \text{ lbs.}$$

b. Weight-weight or volume-volume formula:

This formula is used for mixing dust with dust or liquid with liquid.

Substract:

Percent of active ingredient desired in final product *from* percent of active ingredient in the concentrate.

Equals:

Parts of diluent to use.

Subtract:

Percent of active ingredient in diluent (usually 0) *from* percent of active ingredient desired in final product.

Equals:

Parts of concentrate to use.

Example:

Make 2% water emulsion of chlordane from 46% emulsifiable chlordane and water.

46% minus 2% = 44 = parts of water to add.

2% minus 0% = 2 = parts of concentrate to use.

44:2 = 22:1.

SAFETY MEASURES

It is the responsibility of the surgeon to supervise and advise on safety precautions to be followed in mixing, handling and applying insecticides and rodenticides.

All pesticides should be considered as poisonous, and should be handled by trained personnel under competent supervision. However, if precautions are observed, and if formulations are accurately prepared and applied, there should be no serious effects to workers or to human and animal populations.

a. *Mixing precautions:*

All mixing should be done out-of-doors. Personnel should wear protective rubber gloves and old clothing which can be laundered. Clothing that becomes soaked with pesticides or chemicals should be removed at once and laundered before being worn again. (The use of aprons will prevent this condition.) Spillage on the skin should be removed immediately with soap and water. Respirators are needed when dusts, wettable powders, and most liquids are being mixed.

b. *Storage precautions:*

Installations engineer personnel are responsible for proper storage of pesticides to protect against fire. The Medical Services should insure protection against personal contamination with pesticides. All containers should be clearly labeled as to their contents, and marked "Poison."

c. *Precautions during application of insecticides:*

Except when allethrin and pyrethrine alone are being used, respirators should be worn by all personnel engaged in the application of insecticides.

(1) *Dusts.* Dusting operations require the use of the Type C respirator, with dust filter, or Type B–2 respirator.

(2) *Sprays.* Spraying operations require the use of the Type B–2 respirator; the C respirator is NOT acceptable.

Note: The Type C respirator is lighter weight than the B–2, and is much easier to breathe through, and there is a tendency on the part of control personnel to wear the Type C respirator for spray work for these reasons. This substitution is not authorized, since the C filters are not sufficient to stop the passage of spray droplets.

Rubber gloves should be worn when spray equipment is old and in poor condition, and where there is danger of leakage getting on the operator.

d. *Precautions in utilization of rodenticides:*

The primary precautionary measure to be observed in setting out rat poisons is to place them where there will be a minimum opportunity for humans and other animals to get to them. Placing of bait in places inaccessible to humans and animals, and the use of bait boxes in open areas are recommended.

Zinc phosphide should be mixed out-of-doors on a day when the humidity is low since this poison will release phosgene gas in the presence of moisture.

Calcium cyanide is used in rat burrows outside. No gas mask needed with experienced crews using reasonable care.

e. *Fumigation precautions:*

Precautions to be observed during fumigation are beyond the scope of this chapter. Some fumigants require special canisters in gas masks, and some are highly volatile. Refer to AFM 85-7 for details.

Fumigation is not normally recommended for insect control except in special cases, on advice of an entomologist.

REFERENCES

The reader should insure the currency of listed references.

AFM 85-7, *Military Entomology Operational Handbook.*

AFM 161-3, *Rodent Control.*

AFR 91-21, *Pest Control.*

AFR 91-22, *Aerial Dispersal of Pesticides.*

AFR 160-62, *Joint Utilization of Certain Armed Forces Medical Laboratory Facilities.*

AFR 161-1, *Control of Vector-Borne Diseases.*

AFR 161-3, *Liaison with Public Health Service.*

AFR 161-71, *Disinsection of Aircraft.*

Armed Forces Pest Control Board, *Current Pest Control Recommendations,* Technical Information Memorandum No. 6 (1963). (A revision is expected in the near future.)

USN DVCC, *Recommendations for Chemical Control of Disease Vectors and Economic Pests* (1967).

US Dept. Agriculture, *Collection and Preservation of Insects,* Miscellaneous Publication 601 (1948).

USPHS, Communicable Disease Center, Atlanta, GA., *Rat-Borne Disease, Prevention and Control,* (1940).

USPHS, Communicable Disease Center, Savannah, GA., Annual Report, *Public Health Pesticides.*

Belding, D. L., *Textbook of Clinical Parasitology,* 2d Ed., Appleton-Century-Crofts, New York (1952).

Faust, E. C., *Animal Agents and Vectors of Human Disease,* Lea and Febiger, Philadelphia (1962).

Geary, J. M., *Military Medical Entomology Workbook,* Medical Service School, USAF (1962).

Herms, W. B. and James, M. T., *Medical Entomology,* 5th Edition, MacMillan, New York (1961).

Matheson, R., *Medical Entomology,* 2d Ed., Comstock, Ithaca, New York (1950).

Metcalf, Flint and Metcalf, *Destructive and Useful Insects,* 3d Edition, McGraw-Hill, New York (1951).

Chapter 24

MEDICAL DISASTER PREPAREDNESS FOR NUCLEAR, BIOLOGICAL AND CHEMICAL (NBC) OPERATIONS

The Air Force Disaster Preparedness Program is the consolidation, in a single, comprehensive Air Force-wide program of all plans, programs, and measures essential for effective, timely, and professional response in potential and actual disaster situations. Disaster situations include enemy attack with nuclear, biological, chemical, or conventional weapons; accidents involving nuclear, biological, chemical, or conventional weapons, or components thereof; other accidents resulting in fire, explosion, or uncontrolled environmental release of toxic materials or hazardous electromagnetic radiation; and natural disasters. Although over-all management of the Air Force Disaster Preparedness Program is the responsibility of Operations elements within the Air Force, the Medical Service, obviously, plays a major supporting role.

This chapter concerns medical disaster preparedness, from the Flight Surgeon's point of view, for operations involving nuclear, biological and chemical (NBC) weapons. Since detailed policy, directive, guidance, and technical information concerning NBC weapons or agents are found in numerous Air Force publications, this chapter is designed to tell the Flight Surgeon where to find specific information that he will require for the effective accomplishment of his particular job.

Air Force policy and guidance on NBC disaster preparedness are in the 355 series of regulations and manuals, with which all Flight Surgeons should be familiar. These are listed below:

AFR 355-1	The Air Force Disaster Preparedness Program
AFR 355-5	The National Civil Defense Program
AFR 355-6	The National Plan for Emergency Preparedness
AFR 355-7	Response to Accidents Involving Nuclear Weapons and Materials
AFR 355-8	Military Support in a Civil Defense Emergency
AFM 355-1	Disaster Preparedness—Planning and Operations
AFM 355-2	Armed Forces Doctrine for Chemical and Biological Weapons Employment and Defense

(*Note:* Frequently, Air Force directives are revised, combined, or deleted, and new directives are published as required. The Flight Surgeon must be continuously aware of current directives in the disaster preparedness area.)

USAF Medical Service responsibilities in nuclear, biological and chemical (NBC) operations are broadly covered in the above directives and are specifically delineated in AFR 160-88.

Most, if not all, Flight Surgeons assigned at base level will become involved in local training programs concerning NBC disaster preparedness. Military training requirements in this area are contained in the following:

AFR 355-4	Disaster Preparedness—Training
AFM 50-15	General Military Training
AFP 50-15-2	Disaster Actions and First Aid
UTS 160-1	Disaster Medical Training

Although protective personal equipment for use in NBC operations is not a medical responsibility, the Flight Surgeon is expected to be familiar with the items and their use. A current list of the items is in USAF Table of Allowances 459—Chemical, Biological and Radiological Defense. Information on using this equipment is in AFM 160-37.

Nuclear Warfare

To effectively execute his responsibilities for medical operations prior to, during, and following strategic and/or tactical use of nuclear weapons, the Flight Surgeon must be familiar with the physical and biological effects of nuclear warhead detonation. His best reference source for this information is AFP 136-1-3, that covers in detail the physical as well as the acute and chronic biological effects of heat, blast, prompt ionizing radiation, and delayed ionizing radiation (radioactive fallout). Additional background information on nuclear weapon effects (expressed in less technical terms) is in AFM 160-37, which will also provide the Flight Surgeon with basic guidance for preparation of his input to medical disaster preparedness plans for nuclear warfare.

Detailed information on military fallout shelters, home fallout protection surveys, issuance of AF Form 1173, "Emergency Action Data Card," wartime radiological exposure control procedures, and radiological decontamination is contained in the following:

AFM 88-27	Planning, Design, and Construction of Radioactive Fallout Protection
AFM 160-37	Medical Planning for Disaster Casualty Control
AFM 355-1	Disaster Preparedness—Planning and Operations
AFR 355-16	Emergency War Operations (EWO) Shelters
AFR 355-17	Public Fallout Shelter

Guidance on triage and clinical treatment of nuclear warfare casualties is in the following:

AFM 160-37	Medical Planning for Disaster Casualty Control
AFP 160-2-4	Medical Management of Casualties in Nuclear Warfare

The Air Force medical materiel program for nuclear casualties (MMPNC) is published in section B, volume V, AFM 67-1. This section also contains directives concerning Survival Sited Casualty Treatment Assemblage (SCATA), in which some Flight Surgeons may become involved.

Nuclear Accidents

Because of an intensive safety program involving all aspects of nuclear weapon design and handling procedures, the United States has never experienced an accidental nuclear detonation, although occasional rare accidents involving nuclear weapons have occurred. Such accidents, known as *Broken Arrows*, are ordinarily secondary to crash/burning of aircraft transporting nuclear weapons. As a result of the aircraft crash and fire, the conventional high explosive contained in a nuclear weapon may detonate without producing a nuclear detonation. The result is an immediate personnel hazard of the same magnitude as that caused by the detonation of a conventional high-explosive bomb under the same circumstances. However, Broken Arrows have an associated, potential, long-term personnel hazard in that a nuclear weapon, ruptured from whatever cause, may release unfissioned nuclear fuel into the environment. This unfissioned nuclear fuel consists of solid plutonium and uranium, in the form of finely dispersed airborne particles. Uranium has such insignificant radioactivity that it may be dismissed as a radiation hazard. Plutonium, on the other hand, may constitute a low-level but long-term radiation hazard under certain circumstances. Roughly 24,000 years is required for the radioactive disintegration of 50% of a given quantity of plutonium-239, the plutonium isotope usually associated with Broken Arrows. Therefore, an area contaminated with plutonium-239 may remain a low-level radiation hazard for many years, unless decontamination procedures are undertaken. Plutonium (and uranium) undergo radioactive decay through emission of an alpha particle, which is incapable of penetrating the dead, cornified layer of human skin. Thus, the ionizing radiation emitted by plutonium constitutes no external radiation hazard for the human body. Emission of the alpha particle in the decay of a plutonium or uranium atom is accompanied by the emission of a low-energy gamma ray, which also constitutes no external hazard to the human body. However, this low-energy gamma radiation is often a source of confusion and alarm to inexperienced radiation-monitoring personnel who, believing plutonium and uranium to decay solely by alpha particle emission, erroneously assume that a nuclear detonation must have occurred when they detect gamma radiation at the site of a Broken Arrow. Nuclear fission need not be suspected unless gamma radiation levels in excess of 100 milliroentgens per hour are measured throughout a large area around a Broken Arrow site.

Once plutonium-239 gains access into the human body through inhalation of dust-borne particles or fumes from burning plutonium (or through open wounds), it constitutes a chronic internal ionizing radiation hazard, due to alpha particle irradiation of sensitive tissues, primarily lung and bone. (Because plutonium-239 is relatively insoluble in the gastrointestinal tract, oral intake of this isotope constitutes an insignificant internal radiation hazard.) Most of the plutonium-239 taken into the human body will be eliminated through normal body functions over a period of time — *i.e.*, in urine, feces, and respiratory-tract secretions. However, some fraction of the plutonium-239 will become fixed in tissue, where, after some years of constant alpha irradiation, neoplastic disease may result. A tentative diagnosis of plutonium inhalation can be made immediately after exposure by the simple process of nasal swabbing and subsequent assay for the type and quantity of radioactivity on the swab. Confirmation is made by qualitative and quantitative radioanalysis of the urine or feces. It is important for the Flight Surgeon to realize that a single urine specimen drawn within hours to a few days following exposure, is of little or no value in determining the quantity of plutonium which has been taken into the body, since equilibrium between a body burden of plutonium and the amount excreted in the urine will not be reached until approximately 1 month has elapsed.

Thus, from a medical standpoint, a Broken Arrow ordinarily does not constitute a medical emergency of any greater magnitude than any other aircraft crash/fire involving conventional high explosives. From a preventive medicine standpoint, however, personnel involved in plutonium-239 decontamination operations require intensive medical monitoring to prevent plutonium inhalation. If accidental inhalation of plutonium-239 does occur, the patient must be closely monitored to determine the quantity of plutonium in his body and, when possible, provided with clinical treatment to assist in the elimination of the plutonium from his body.

The maximum permissible quantity of plutonium-239 in the body is 0.44 microcuries. This quantity is called 1 body burden, and laboratory assays of body excretions to determine plutonium-239 levels are expressed in terms of body burdens. A fractional body burden less than 1 is expressed in terms of percent of 1 body burden.

A single permissible contamination level for plutonium-239 which is valid in all geographical locations under all circumstances cannot be established, due to a variety of factors determining the actual hazard in each case. Such factors include terrain, soil composition, annual rainfall, intensity and direction of prevailing winds, population density, and amount of normal vehicular traffic which resuspends deposited plutonium-239 in the resulting dust. Whether or not the contaminated area remains under Federal control is another important consideration. Every feasible attempt must be made to decontaminate to zero level. Often, however, low levels of residual plutonium-239 contamination become "fixed," particularly on coarse surfaces, in which case, further decontamination cannot be accomplished without extensive damage. In such instances, the following contamination limits apply on Air Force installations, but only after repeated attempts have been made to decontaminate to a zero level:

Maximum Permissible Contamination Limits of Fixed Plutonium-239 (or Equivalent Alpha-Emitting Radioisotopes) Which Remain Under Air Force Control

1. *Equipment and Materiel:* 450 counts per minute recorded on the PAC-1S alpha radiation survey meter.
2. *Clothing, Shoes, and Personal Equipment When Worn:* 450 counts per minute recorded on the PAC-1S alpha radiation survey meter.
3. *Human Skin:* 450 counts per minute recorded on the PAC-1S alpha radiation survey meter.
4. *Geographically Isolated Areas:* 1000 micrograms per square meter of ground surface recorded on any alpha radiation survey meter.

Detailed policy, guidance and background information on the Air Force nuclear safety program and handling of Broken Arrows are contained in the following:

AFR 122-1	Responsibilities for the AF Nuclear Safety Program
AFR 355-7	Response to Accidents Involving Nuclear Weapons and Materials
AFM 35-99	Human Reliability Program
AFM 122-1	The Nuclear Weapon Safety Program
AFM 160-37	Medical Planning for Disaster Casualty Control
AFM 355-1	Disaster Preparedness—Planning and Operations
AFP 92-1-1	Fire Fighting Guidance —Nuclear Weapons

Since many of the medical operations during and following a Broken Arrow are routine procedures under the USAF Health Physics Program, the Flight Surgeon must be familiar with the following directives, all of which also apply to the routine occupational medicine program on any base:

AFR 160-132	Control of Radiological Health Hazards
AFR 161-8	Control and Recording Procedures — Occupational Exposure to Ionizing Radiation
AFR 161-11	Film Dosimetry Program
AFR 161-17	Environmental Health, Forensic Toxicology, and Radiological Health Professional Support Functions

The Flight Surgeon who becomes involved in Broken Arrow operations must be aware of the extensive specialized assistance that is available to him through the USAF Radiological Health Laboratory, Wright-Patterson Air Force Base, Ohio. The services available through this Laboratory consist of both bio-assay procedures and clinical consultation. Procedures for forwarding bio-assay samples and for obtaining professional consultation are in AFR 161-17. Assistance and consultation in the nuclear accident area are also available through Bioenvironmental Engineers (AFSC 9121 and 9124), Health Physicists (AFSC 9171 and 9176) and Medical Officers, Special Weapons Defense (AFSC 9646).

Biological and Chemical Warfare

In planning medical preparedness for biological and chemical warfare, it is important that the Flight Surgeon bear in mind that he is not being confronted with a new and previously unknown entity. Physicians regularly see and treat infectious disease as part of their normal clinical practice, and problems in diagnosis are common, particularly when diagnosing infectious diseases which are of rare occurrence in a given geographical area. By the same token, the average physician routinely sees and treats cases of poisoning from toxic chemicals. For the most part, biological and chemical warfare agents, or at least the type of disease or poisoning which they produce, are not unique to this form of warfare.

Guidance and background information on potential biological and chemical warfare agents are in the following:

AFM 160–37	Medical Planning for Disaster Casualty Control
AFM 355–1	Disaster Preparedness—Planning and Operations
AFM 355–2	Armed Forces Doctrine for Chemical and Biological Weapons Employment and Defense
AFM 355–4	Employment of Chemical and Biological Agents
AFM 355–5	(S) (Gp–1) Employment of Biological Agents
AFM 355–6	Military Biology and Biological Agents
AFM 355–7	Military Chemistry and Chemical Agents
AFM 355–9	(C) Employment of Chemical Agents

Guidance on clinical diagnosis and treatment of biological and chemical warfare agents can be found in detail in the following:

AFM 160–37	Medical Planning for Disaster Casualty Control
AFM 160–12	Treatment of Chemical Warfare Casualties
AFM 355–6	Military Biology and Biological Agents
AFM 355–7	Military Chemistry and Chemical Agents

Guidance on the Air Force medical materiel program for defense against biological and chemical (BW/CW) warfare agents is in section C, volume V, AFM 67–1, USAF Supply Manual.

Biological and chemical decontamination procedures for use on contaminated materiel and ground areas, are in AFM 355–1.

Biological and Chemical Agent Accidents

In terms of local disaster preparedness, accidental release of biological and chemical agents into the environment will produce the same clinical effects as intentional release from a weapon in warfare. Thus, the policy guidance and background information contained under the preceding section on Biological and Chemical Warfare, are also applicable to the accident situation. The Air Force conducts an intensive safety program to prevent accidents involving biological and chemical agents and to handle such accidents should they occur. Responsibilities under this program are in AFR 136–4, "Responsibilities for Technical Escorts of Chemical, Biological and Etiological Agents." Additional background information of value to the Flight Surgeon may be found in AFM 71–4, "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft," and 160–39, "Handling and Storage of Liquid Propellants."

Chapter 25

SPACE MEDICINE

The origin of aviation medicine as a clinical discipline in the United States may be specified rather accurately by the Secretary of War's order to the Surgeon General, in 1912, to prepare a special examination for Aviation School candidates.

Thirty-six years later, *space medicine* was recognized as an entity by a symposium on the subject and, shortly thereafter, in 1949, by the creation of a Department of Space Medicine. Both events occurred at the School of Aviation Medicine at Randolph Air Force Base.

This is not to say that there was, in 1948, or is, even now, a clear delineation between aviation medicine and space medicine, particularly from the clinical point of view. Many, if not most, of the physiological problems of space flight are also the problems of aviation medicine. Some of these, such as the effects of cold, oxygen deprivation, and fear, had been identified as early as the 18th century through the balloon flights of Professor Jacques Charles, Dr. John Sheldon, and others. Reports by these aerialists of the anomalies of physiological response encountered in high altitude flight led to more scientific levels of reporting during the 19th century, when records of body responses during flight were kept in greater detail. Glaisher and Coxwell, for example, who reached almost 6 miles in altitude, reported, meticulously, their medical findings during their flight. In 1901, Professor A. Berson and Dr. R. J. Suring, equipped with special clothing, adequate oxygen, and devices designed for ready and reliable altitude control, became the first to reach the stratosphere. Knowledge gained from personal experience and from reports of earlier balloonists had well prepared them for this venture.

It is interesting to observe that some of the medical problems that were incidental to later high-altitude aircraft and space flight, were more the problems of the early balloonists than they were of the aviators in the pre-World War I days of powered flight.

The later balloon flights of Picard and Kipfer, Settle and Fordney, Anderson and Stevens, Simons, and Kittinger (102,800 feet) all provided more detail of the physical and physiological hazards of high altitudes, as did the powered flights of men like the US Army's Schroeder (33,113 feet) and Macready (38,704 feet), and the Navy's Soucek (43,166 feet) in 1930.

Since, from the point of view of the human organism, the dividing line between the earth's atmosphere and space is often considered to be about 43,000 feet in altitude, it will be apparent that space flight, in the broad definition, did occur long before the symposium at Randolph Air Force Base in 1948, and that those in the field of aviation medicine were interested in and worked on problems which were associated with these activities. However, space medicine, until the time of the Soviet's Vostok I, in 1961, remained, for the most part, a research-oriented discipline, and it was only with the advent of NASA's Project Mercury that it became a clinical entity in the United States.

Broadly, *space medicine*, as does its synonym "bioastronautics," *relates to the selection, support, and care of an astronaut and the life support of operations in space.* In a more specific operational definition, the purview of space medicine would include:

a. Providing the body of knowledge and the human standards required for the design and engineering of space vehicles intended for manned missions.

b. Providing the body of knowledge essential to the development and effective operation of crew-protective and life support systems.

c. Identifying and studying, through ground-based studies or in-flight experiments, space flight stresses and their psychophysiological effects.

d. Establishing the medical standards for the selection of astronauts and for their continuing medical care.

e. Providing the medical supervision, indoctrination, and experimental familiarization with aspects of the astronaut training program, such as centrifuge and chamber operations.

f. Providing the preflight medical preparation of the astronaut and the postflight medical observation and care.

g. Developing the medical protocol for the operational support of manned missions and providing the medical support at launching sites, tracking stations, and in recovery and rescue operations.

h. Evaluating the medical results of manned space missions.

i. Devising and developing means of increasing the body of biomedical knowledge, whether through experiment or analysis of flight medical data, to provide the basis for planning flights of extended duration and for estimating and providing for man's capability to function on planetary surfaces.

j. Devising and developing means of protecting the earth's atmosphere, population, and living resources from a possible back-contamination from extraterrestrial sources.

The final definition of space medicine, then, is that it is a discipline which, within the broad frame of preventive medicine, is concerned with the development of information and techniques to prepare man for adventures in space; the support of man during space and planetary exploration; and the protection of man and his terrestrial environment from the hazards of space. This chapter will consider the medical contributions to the achievement of manned space flight and the medical results of the manned space missions.

THE UNITED STATES MANNED SPACE FLIGHT PROGRAM

Studies, during the International Geophysical Year (1 July 1957 to 31 December 1959), indicate that there is no clearly defined point at which the earth's atmosphere may be said to end and space to begin.

The absence of a specific physical definition for space, however, imposes no restrictions in defining the medical aspects of space, for, as early as 1951, Strughold, Haber, *et al.*, suggested that the dividing line between the atmosphere and space occurs at different altitudes for different physiological functions. This, they referred to as *Space Equivalence* or the *Functional Border of Space*. Strughold's concept presents not only a meaningful frame of reference in which to work, but it also emphasizes the close relationship between aviation medicine and space medicine.

The United States manned space flight program was planned on an incremental basis, each flight extending somewhat the stresses experienced previously, or investigating new parameters. There were, therefore, short-duration flights before longer ones, single-man crews before multiman crews, and various other instances of increased activity and progressive application of experience and knowledge previously gained. The incremental progression is evidenced clearly not only in the different objectives of the major projects of Mercury, Gemini, and Apollo, but also in the objectives and planned sequence of events which identify the individual missions within a given project.

For all practical purposes, the manned space flight program in the United States began with Project Mercury, definitive efforts toward which were initiated in 1958. The activity under Project Mercury which established space medicine as a clinical entity rather than, solely, a research effort, was the medical selection of astronauts.

MEDICAL SELECTION OF ASTRONAUTS

By command decision, the first astronauts were to be chosen from among the military test pilots on active duty who volunteered their services and who were both homogeneous in terms of experience and highly motivated by a keen interest in the space program. Thus, they were to be a highly select group in the medical sense.

Men were selected in two phases. In the first phase, the records of all military test pilots were reviewed and screened in accordance with the basic criteria established, such as graduation from a test-pilot school, a minimum of 1,500 flying hours, qualification in high-performance jet aircraft, age not to exceed 39 years, and height not in excess of 71 inches. On the basis of the results of this screening, prospective candidates were reduced in number to 69. These candidates were, then, assembled in Washington DC, where they were interviewed, provided with technical details of the project, and given the opportunity to volunteer or decline. Medical records of those who volunteered were reviewed again in greater detail. In addition, psychiatric and psychological examinations were given these volunteers. Thirty-two were selected for the second phase of the selection process. Thirty-one completed the series of examinations. The second phase consisted of intensive medical examination at the Lovelace Clinic in Albuquerque, New Mexico, and psychological and stress testing at the Aerospace Medical Laboratory at Wright-Patterson Air Force Base.

Medical Examination

Basic to the medical examination were the medical and aviation histories. The former, in addition to the conventional medical and family history, included investigation into the attitude of the immediate family toward hazardous flying; the candidate's growth, development, and education; travel in areas where parasitic diseases were endemic; and tendency to disorders which precluded pressure inflation of the sinuses, lungs, or ears. The aviation history included information on total flying hours, war and peacetime military experiences, and operational experience with pressure suits.

The physical examination was conducted by flight surgeons, internists, and other appropriate specialists, including an ophthalmologist, otolaryngologist, neurologist, and cardiologist.

Laboratory tests conducted during the course of the examination are shown in table 25–1. Roentgenograms were made of the teeth, sinuses, thorax, esophagus, stomach, colon, and lumbosacral spine. Cineradiograms were made of the heart.

To estimate the candidate's general condition, physical competence measurements were made, including various vital capacity tests and a bicycle ergometer test under electrocardiograph monitoring. A summary of pertinent physiological data is provided in table 25–2.

Psychological and Stress Testing

The intent of the psychological tests administered at the Aerospace Medical Laboratory was to determine, on the one hand, personality and motivation and, on the other, intelligence and special aptitudes. A variety of standardized tests were used in both instances. Although the complete listing of tests will not be discussed here, it is interesting to note that the personality-motivation series included, in addition to such standard items as the Rorschach and Thematic Apperception Test, the Officer Effectiveness Inventory. The intelligence-special aptitudes group included the Air Force Qualification Test, the Navy's Aviation Qualification Test, the Wechsler Adult Scale, and a variety of analogies, comprehension, and spatial orientation tests.

The astronaut candidates were subjected to a large number of stress tests of both a psychological and physiological nature. These included the Harvard Step Test, a treadmill workload test, tilt-table test, and a cold-pressor test. Other stresses to which the candidates were exposed were noise, vibration, acceleration, isolation (3 hours in a dark, soundproof room), a simulated altitude

TABLE 25-1. LABORATORY TESTS (MERCURY ASTRONAUT SELECTION)

Test	Astronaut candidates (31)		Astronauts selected (7)	
	Mean	Range	Mean	Range
*Hemoglobin, gm/100 ml	16. 0	14. 5–17. 9	16. 6	14. 5–16. 2
Total circ. hemoglobin, gm	756. 5	565–1,127	857. 2	674–1,120
*Leukocytes, 1,000/mm³	8. 1	4. 7–15. 3	7. 7	5. 0–10. 0
*Sedimentation rate, mm/hr	5	0–32	4	2–6
*Cholesterol, mg/ml	225	150–320	238	184–280
*Sodium, meq/l	142	139–147	143	141–144
*Potassium, meq/l	4. 6	3. 4–5. 5	4. 7	4. 0–5. 5
*Chlorine, meq/l	105	103–110	10. 5	103–108
*Carbon dioxide, meq/l	26	22–30	26	23–30
*Sugar, mg/100 ml	102	84–112	100	88–108
*Protein bound iodine, μgm/100 ml	5. 8	4. 2–10. 4	5. 5	4. 9–6
*Bromsulphalein, % retention (45 min)	3	0–7	3	2–4
17-ketogenic steroids, mg/24 hr	19. 1	8. 8–29	18. 3	11. 1–23
17-ketosteroids, mg/24 hr	13. 7	8–22. 6	13. 3	9. 9–17. 5

*Fasting specimen.

TABLE 25-2. PHYSIOLOGICAL DATA (MERCURY ASTRONAUT SELECTION)

Test	Astronaut candidates (31)		Astronauts selected (7)	
	Mean	Range	Mean	Range
Height, cm	176	167–180	177	170–180
Weight, kg	73. 4	61–87	75. 3	70–87
Body surface area, m²	1. 9	1. 7–2. 1	1. 9	1. 8–2. 1
Lean body mass, kg	63. 9	55–71	66. 8	59–71
Total body potassium, gm	168. 6	142–204	175. 4	167–199
Total body water, liters	41. 3	36–47	41. 5	37–45
Blood volume, liters	4. 92	3. 33–6. 91	5. 40	4. 35–6. 91
Total circ. hemoglobin, gm	756. 5	565–1,127	857. 2	674–1,120
Total lung capacity, liters	6. 82	5. 36–8. 19	7. 02	6. 34–8. 02
Functional residual capacity, liters	3. 22	2. 25–4. 23	3. 41	2. 96–4. 23
Vital capacity, liters	5. 49	4. 35–6. 91	5. 54	5. 11–6. 02
Residual volume, liters	1. 32	0. 83–2. 00	1. 48	1. 13–2. 00
Maximum breathing capacity, liters	180	149–247	191	156–247
Nitrogen clearance equivalent	11. 1	9. 3–13. 0	10. 9	9. 2–12. 0
Final O_2 uptake during exercise, l/min	2. 41	1. 90–2. 84	2. 60	2. 07–2. 84

of 65,000 feet in an MC-1 partial pressure suit, and a complex behavior simulator.

The final evaluation of the candidates, made jointly by representatives of the Aerospace Medical Laboratory, the Lovelace Clinic, and medical and technical activities in NASA, resulted in the selection of seven astronauts.

With the exception of the requirement that the candidate be a test pilot and qualified in high-performance aircraft, selection criteria, standards, and techniques for Gemini and Apollo astronauts varied only slightly from those originally established.

MEDICAL SUPPORT OF FLIGHT AND RECOVERY OPERATIONS

A significant aspect of a manned space flight mission is the medical support of flight and recovery operations. The group that provides this support serve:

a. As aeromedical monitors, assigned to network tracking stations, to observe the physiological condition of the astronaut during flight.

b. At the launch site to provide emergency surgical support in the event of an incident.

c. On recovery vessels to provide immediate medical assistance in the event of an emergency during recovery.

d. At advanced medical units in high probability landing areas.

e. At the launch site to assist in preflight medical preparations.

f. As medical flight controllers at the Mission Control Center to determine whether the astronaut is capable of continuing a mission from a physiological point of view.

These needs are met by flight surgeons and other medical specialists, nurses, dietitians, and medical technicians, the majority of which are military personnel. Further support, in the form of medical specialty teams, has been provided by the Wilford Hall USAF Hospital, Lackland AFB, the US Naval Hospital, Portsmouth, Va., the Walter Reed Army Hospital, Washington, DC, and the Tripler General Hospital, Honolulu.

Medical Monitoring

Since the safety and welfare of the astronaut, both in training and flight, comprise a basic doctrine within the philosophy of the United States manned space flight program, the possibility of a requirement for a medical decision during flight is evident. Logically, it follows that there would be a necessity for means by which to observe physiological responses during flight, sources of evaluation, and a point of medical decision concerning continuation of the mission.

The continuous monitoring of physiological data taken from a pilot during a test flight is a relatively recent concept. In fact, at the time Project Mercury was to be undertaken, suitable techniques for reliably measuring the desired physiological parameters for prolonged flight were not readily available. Therefore, in the interest of flight safety, it was decided, at the beginning of the Mercury series, to attempt to monitor body temperature, chest movement, and heart action. The standards for devising techniques to accomplish this objective required that the sensors and equipment be comfortable, reliable, compatible with other spacecraft systems, and not interfere with the astronaut's primary mission.

The physiological parameters monitored and the changes and problems with respect to sensors can be summarized as follows: In the Mercury missions, body temperature was monitored with a rectal thermistor. This procedure was later modified, using an oral thermistor. The range of the thermistor was also changed to permit it to record suit-outlet temperature when it was in the stowed position on the right ear muff.

At first, respiration was measured by an indirect method, using a linear potentiometer and carbon-impregnated rubber. Early in the program, this method was changed to a thermistor kept at 200° F and placed on the microphone pedestal in the helmet. Since neither of these methods gave reliable respiration traces during flight, another method was employed during the last two Mercury missions, using the impedance pneumograph.

Electrocardiographic electrodes were of a low impedance to match the spacecraft amplifier. They were required to record during body movements and to stay effective during flight durations of over 30 hours. The electrodes functioned well and gave very good information on cardiac rate and rhythm. The value of having two leads of electrocardiograph, even though they differed from the standard clinical leads, was shown repeatedly. This allowed easier determination of artifacts and was most helpful in determining the valid sounds on the blood-pressure trace by comparison with the remaining ECG lead. The electrode paste was changed from 30% calcium chloride in water mixed with bentonite, to a combination of carboxypolymethylene in Ringer's solution. The 10 times isotonic Ringer solution not only retained the necessary conductivity and low impedance required, but also afforded decreased skin irritation after prolonged contact.

In 1958, the obtaining of blood pressures in flight was considered and then delayed, as no satisfactory system was available. Definitive work began about the time of the first manned suborbital Mercury flight, and the automatic system which used the unidirectional microphone and cuff was developed for use in the orbital flights. This system without the automatic feature was used on the first manned orbital mission. During the second manned orbital mission, all of the in-flight blood pressures obtained were elevated, and an extensive postflight evaluation program was undertaken. It was determined that the cause of these elevations was most likely instrumentation error resulting from the necessity for very careful gain settings matched to the individual astronaut along with the cuff and microphone. A great deal of preflight calibration and matching of these settings was done prior to the last two missions, and in both instances, excellent blood-pressure tracings were obtained.

Voice transmissions can be a very valuable source of monitoring information. Normal flight reports and answers to queries have been used for evaluating the pilot. In addition to normal reports, verifying the actual comfort level was valuable in determining the importance of temperature readings obtained by way of telemetry. In-flight photography and, in later missions, television views of the astronaut were used as additional data sources. In early experience, both of these sources proved to be of little value in the medical monitoring of the astronaut because of poor camera positioning and varying lighting conditions resulting from the operational situation.

The value of the comparison of multiple physiological parameters and their correlation with environmental data has been proven repeatedly. Abnormal or lost values attributed to instrumentation difficulty have been obtained frequently, but it has been found that interpretation of the astronaut's physiological condition could be made by the use of the parameters remaining or the correlation of those remaining with environmental data.

Flight experience thus far has shown that a satisfactory amount of information on current astronaut status can be obtained with the use of such basic vital signs or viability measures.

Considerable experience in the medical flight control of an orbiting astronaut was obtained through the use of range simulations and the actual flights. It was apparent that the development of mission rules to aid in flight control was necessary in the medical area, just as it was in the many engineering areas, and definite number-value cutoffs for various medical parameters were established early in the program. Gradually, the rules were made less specific. Consequently, the evaluation and judgment of the medical flight controller became the prime determinants in making a decision. The condition of the astronaut, which was determined by voice and interrogation rather than by physical parameters alone, became a key factor in the medical decision to continue or terminate the mission.

Recovery

The medical support of mission recovery

operations must fulfill two basic requirements:

a. Provide prompt, optimum medical care for the astronaut, if necessary, upon his retrieval from the spacecraft.

b. Conduct an early medical evaluation of the astronaut's postflight condition.

It is considered essential to establish a medical capability for any circumstance under which recovery could occur. The general concept is to provide the best care as fast as possible. Original plans were necessarily based on anticipation of the direst situation possible.

The extent to which medical care can be effectively administered to the astronaut during the recovery operation is governed, to a large degree, by the physical circumstances under which recovery occurs. Medical support at the different recovery areas varies according to the area potential for administration of competent medical treatment. The most extensive medical support is concentrated in the areas where descent to earth by the astronaut is most probable.

Access times for the various recovery areas were established to provide medically acceptable time periods that would afford the astronaut reasonable protection. These time periods were based upon accumulated knowledge of human survival, need for medical attention, and reaction to physiologic stress.

One of the basic changes in philosophy occurring during the program concerned the medical care of the astronaut. In the early missions, the emphasis was on bringing medical aid to the site of recovery. In the later missions, provisions were made to return the astronaut to definitive medical care centers as required.

Medical support is provided for three basic categories:

(1) Rapid crew egress and launch-complex rescue capability during the late countdown and early phases of powered flight.

(2) Positive short-time recovery capability throughout all phases of powered flight and landing at the end of each orbital pass.

(3) Reduced capability in support of an unplanned landing along the orbital track.

In the launch-site area, this support includes a medical-specialty team consisting of a general surgeon, an anesthesiologist, surgical technicians and nurses, a thoracic surgeon, an orthopedic surgeon, a neurosurgeon, an internist, a radiologist, a pathologist, a urologist, a plastic surgeon, and supporting technicians. In the early missions, this team was deployed to Cape Kennedy to be available when needed at the Cape or in the recovery area, to which they were transported by aircraft. For the last two Mercury missions, a team was activated at Tripler General Hospital, Hawaii, to cover the Pacific area as well. When it became obvious that there were large numbers of highly trained physicians who were merely waiting out the mission in a deployed state and, more than likely, would not be used, the conclusion was reached that specialty teams could be maintained on standby at Stateside hospitals and easily flown to the Cape or a recovery site.

Other launch-site support is provided by a point team consisting of a flight surgeon and scuba-equipped pararescue personnel, airborne in a helicopter. Medical technicians, capable of rendering first aid care, are also available in Lighter Amphibious Resupply Cargo (LARC) vehicles and in small water jet boats. A surgeon and an anesthesiologist, along with their supporting personnel, are stationed in a blockhouse at Cape Kennedy to serve as the first echelon of resuscitative medical care in the event of an emergency. Physicians are stationed throughout the recovery areas in the Atlantic and Pacific, aboard destroyers and aircraft carriers. In the early missions, each vessel was assigned a team comprising a surgeon, anesthesiologist, and medical technician, along with a supporting medical equipment chest, necessary for evaluation and medical or surgical care. As confidence was gained in the operations, the number and distribution of medical personnel were modified.

Postflight medical data is collected at the earliest opportunity. Immediately after the hatch is opened, an extension cord for the biomedical cable may be attached to the astronaut's biosensor plug and blood-pressure fitting, and connected to the spacecraft onboard recorder to record blood pressures and ECG before, during, and after egress. This system is extremely effective in deriving egress data.

The postflight activities of the pilot of Mercury-Atlas 9, the fourth manned orbital mission, are shown in table 25-3, as an example of the medical procedures observed.

PHYSIOLOGICAL RESPONSES IN SPACE FLIGHT

The United States manned space flight program has included three projects: Mercury, Gemini, and Apollo (see figure 25-1).

The first of these was Mercury. Its objective was to place a man into orbit and return him safely to earth. This objective was accomplished in February 1962, in a mission which extended over a period of 4 hours and 55 minutes (see table 25-4).

The second project, Gemini, was an essential interim program directed toward achievement of the national objective of landing a man on the moon and returning him safely to earth. The Gemini program was a logical follow-on program after Mercury which minimized time and expense and was designed to subject two men and necessary supporting equipment to long-duration flights, thus, accumulating the experience and knowledge necessary for trips to the moon and beyond (see table 25-5). A specific objective was to achieve rendezvous and docking with another orbiting vehicle and maneuver the combined spacecraft (a key element of the approach selected for the lunar project). The major medical objectives were the accumulation of experience with the effects of weightlessness and the physiological reactions of crew members during

TABLE 25-3. POSTFLIGHT ACTIVITIES, MA-9

Date, 1963	Time, local Midway [a]	Activity
May 16	12:25 p.m.	Landing.
	12:55 p.m.	Spacecraft on deck.
	1:09 p.m.	Blood pressure, recumbent in spacecraft.
	1:12 p.m.	Egress and blood pressure standing.
	1:15 p.m.	Physical examination begun in recovery ship sick bay.
	1:45 p.m.	First tilt table procedure.
	3:00 p.m.	Examination completed.
	3:30 p.m.	First postflight urination.
	3:42 p.m.	Second tilt table procedure.
	4:10 p.m.	First postflight meal.
	5:45 p.m.	First postflight bowel movement.
	7:11 p.m.	Third tilt table procedure.
	9:30 p.m.	To bed.
May 17	7:00 a.m.	Awakened.
	7:40 a.m.	Fourth tilt table procedure and brief medical examination.
	8:00 a.m.	Breakfast.
	9:00 to 11:00 a.m.	Self-debriefing.
	2:00 to 5:00 p.m.	Technical debriefing.
	7:00 to 9:00 p.m.	Medical debriefing.
May 18	1:00 p.m.	Left recovery ship.
May 20	9:00 a.m. e.s.t.	Comprehensive postflight medical examination at Patrick Air Force Base, Fla.

[a] To convert times to e.s.t., add 6 hours.

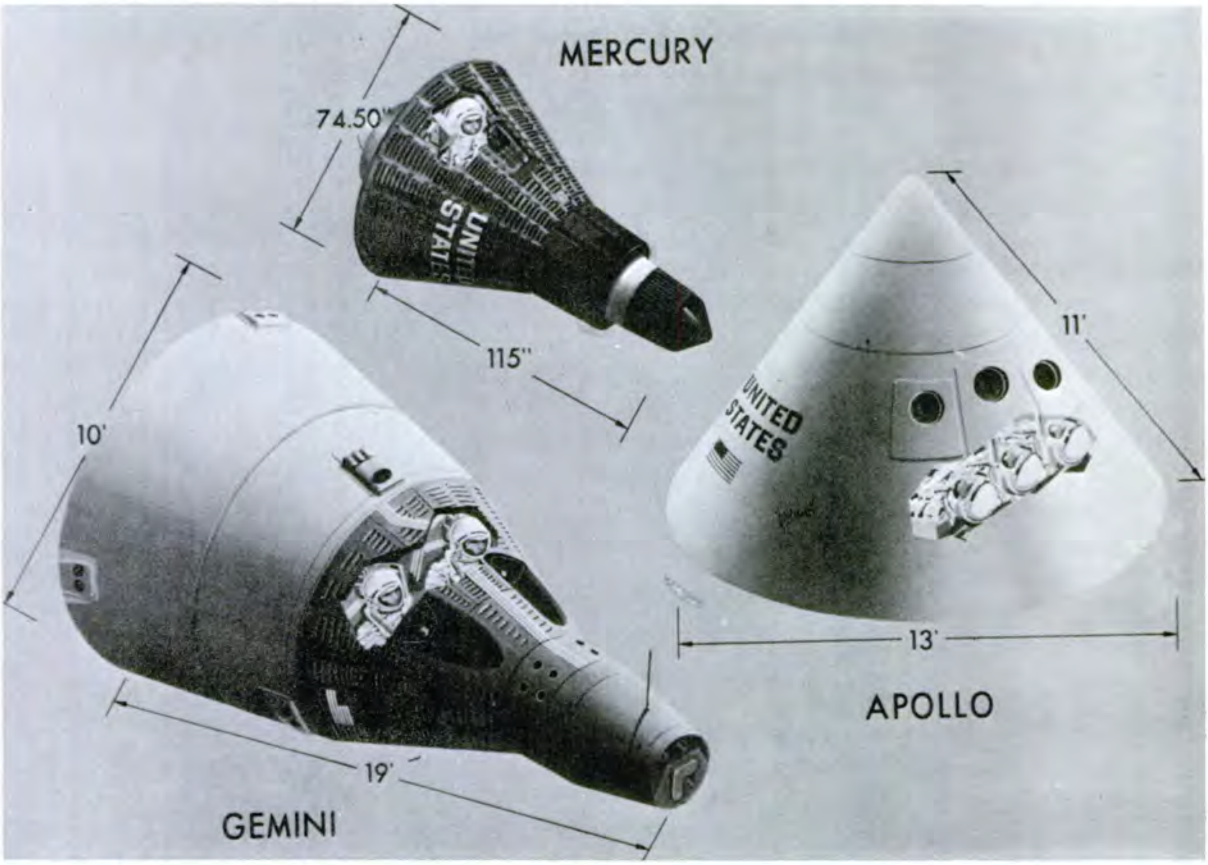


Figure 25–1. US Manned Flights.

long-duration missions, and the compilation of medical data necessary for planning missions in later programs. The Gemini spacecraft was, in many ways, a two-man orbiting laboratory through which knowledge of and experience in the space environment were increased considerably. The Gemini series was terminated with the flight of Gemini 12.

The third planned project is Apollo which has the objectives of lunar landing and exploration, using a three-man crew.

Before the first manned orbital flights, many predictions were made concerning the possible adverse effects of space flight. Since weightlessness was the one unknown factor that could not be duplicated exactly in a laboratory situation on the ground, some effect on almost every body system was predicted. These were anticipated on the basis of known influences of gravity on certain body systems, on the knowledge of effects of disease phenomena, and within the context of ground-based research and clinical observation. Vestibular and proprioceptive disturbances were anticipated not only on a theoretical basis, but also as a result of the reported appearance of symptoms in the case of Major Gheman Titov, the Russian Cosmonaut, during his 17.5 orbit flight in 1961. Since the cardiovascular system is markedly influenced by gravity, disturbances in the weightless condition were expected. On the basis of ground-based research in sensory deprivation, there was some expectation of hallucinations. The possibility of impairment of crew performance due to disturbance of circadian rhythm was also considered. None of these was significant in Mercury. However, the Mercury experience did define physiological problem areas on a more realistic basis.

TABLE 25-4. MERCURY MANNED FLIGHT SUMMARY

Mission *	Launch Date	Flight Duration # HR:MIN:SEC	Basic Test Objectives
MR-3...Manned	5 May 1961	00:15:22	Suborbital flight; familiarize man with space flight; evaluate response and S/C control.
MR-4...Manned	21 Jul 1961	00:15:37	Suborbital flight; same as MR-3.
MA-4...Unmanned	13 Sep 1961	01:49:20	One-pass orbital flight; same as MA-3.
MA-5...Unmanned	29 Nov 1961	03:20:59	Three-pass orbital flight; qualify all systems, network, for orbital flight recovery.
MA-6...Manned	20 Feb 1962	04:55:23	Three-pass orbital flight; evaluate effects on and performance of astronaut in space; astronaut's evaluation of S/C and support.
MA-7...Manned	24 May 1962	04:56:05	Three-pass orbital flight; same as MA-6; evaluate S/C modifications and network.
MA-8...Manned	3 Oct 1962	09:13:11	Six-pass orbital flight; same as MA-6 and MA-7 except for extended duration.
MA-9...Manned	15 May 1963	34:19:49	Twenty-two pass orbital flight; evaluate effects on man of up to 1 day in space; verify man as primary S/C system.

* MR - Mercury-Redstone Launch Vehicle; MA - Mercury-Atlas Launch Vehicle

Duration measured from lift-off to landing

TABLE 25–5. GEMINI MANNED FLIGHT SUMMARY

Mission	Launch Date	Duration *	Base Test Objectives
Gemini 3	23 Mar 1965	4 hours	Manned qualification of Gemini Spacecraft.
Gemini 4	3 Jun 1965	4 days	EVA and systems performance for 4 days.
Gemini 5	21 Aug 1965	8 days	Long-duration flight, rendezvous radar capability.
Gemini 7	4 Dec 1965	14 days	2-week duration flight, evaluation "shirt-sleeve" environment, controlled re-entry.
Gemini 6A	15 Dec 1965	1 day	On-time launch procedures, closed-loop rendezvous.
Gemini 8	16 Mar 1966	10 hours	Rendezvous and docking, controlled re-entry, parking.
Gemini 9A	3 Jun 1966	3 days	Rendezvous and docking, extravehicular activity.
Gemini 10	18 Jul 1966	3 days	Rendezvous and docking, extravehicular activity, experiments.
Gemini 11	12 Sep 1966	3 days	First revolution rendezvous and docking, docking practice, tethered vehicle test, automatic re-entry.
Gemini 12	11 Nov 1966	4 days	Rendezvous and docking, docking practice, station-keeping exercise, maneuvers.

* Approximate

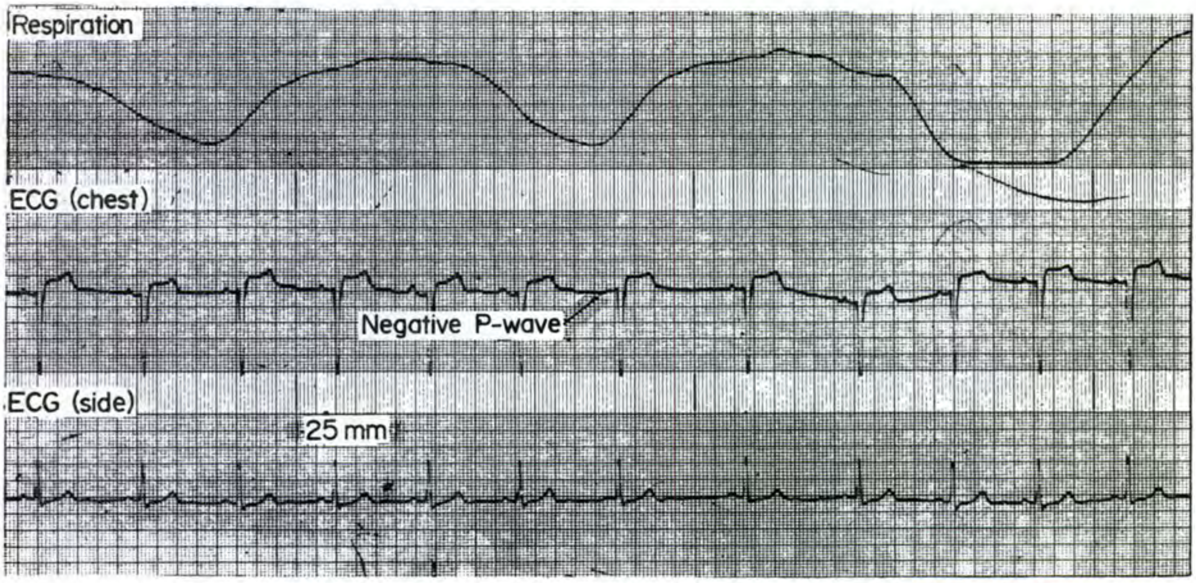
In studying the physiological responses of man in space flight, it is important to remember that there are multiple stresses acting upon him, thus complicating the analysis of any given response. Man must undergo a number of stresses in reaching, staying in, and departing the orbital environment. These stresses may include such factors as the full pressure suit, confinement and restraint, 100% oxygen and 5-psia atmosphere, changing cabin pressure (launch and reentry), varying cabin and suit temperatures, acceleration G-force, weightlessness, vibration, dehydration, flight-plan performance, sleep need, alertness need, changing illumination, and diminished food intake. Any one of these stresses will always be difficult to isolate; however, in a sense, it could be said that this fact is only of limited interest, for the results would always represent the effects of man's exposure to the total space flight environment. In attempting to examine the effects of a particular space flight stress, such as weightlessness, it must be realized that the responses observed may, indeed, be complicated by other factors, such as physical confinement, acceleration, dehydration, or the thermal environment.

In considering the physiological responses in space flight, it is necessary to have a detailed in-flight event history since peak physiological responses are closely related to critical in-flight events. This meaningful relationship is well demonstrated by pulse rate responses during flight (see table 25-6). Peak pulse rates during a launch phase usually occurred at sustainer-engine cutoff. This peak value in Mercury ranged from 96 to 162 beats per minute. The peak rates obtained on reentry ranged from 104 to 184 beats per minute. This usually occurred immediately after obtaining peak reentry acceleration, or on drogue parachute deployment. Pulse rates obtained during weightless flight varied from 50 to 60 beats per minute during the sleep periods to 80 to 100 beats per minute during the normal wakeful periods. Elevated rates during weightless flight were usually related to flight-plan activity. Respiratory rates ranged from 30 to 40 breaths per minute at sustainer-engine cutoff, from 8 to 20 breaths per minute during weightless flight, and from 20 to 32 breaths per minute at reentry. Changes noted in electrocardiograms included alterations in the pacemaker activity with wandering pacemakers and aberrant rhythm, including atrioventricular nodal beats and rhythm, premature atrial and ventricular contractions, sinus bradycardia, atrial rhythm, and atrioventricular contraction (see figures 25-2 and 25-3). All of these "abnormalities" can be considered normal physiological responses when related to the dynamic situation in which they were encountered.

Considerable progress was made in acquiring medical data and in understanding man's physiological and psychological reactions in the space environment during the relatively short time the Mercury and Gemini programs were in being. In May of 1963, it was predicted that man could live and work in a space environment for at least four days, as long as adequate life support was provided. A 14-day mission and additional flights followed which provided both rendezvous and extravehicular activity experience. At the end of 1966, 19 men had been exposed to a total weightless experience of about 1900 man-hours. Three astronauts had flown both single and dual-crew vehicles, and four had flown twice in the Gemini capsule. A comparison of data on the seven persons twice exposed to space flight reveals that, while this experience does alter some of the mental attitudes and performance, it

TABLE 25-6. PULSE RATES

Mission	SECO (Peak)	Weightlessness (Range)	Re-entry (Peak)
MR-3	138	108 to 125	132
MR-4	162	150 to 160	171
MA-6	114	88 to 114	134
MA-7	96	60 to 94	104
MA-8	112	56 to 121	104
MA-9	144	50 to 60 (sleep) 80 to 100 (awake)	184



This sample illustrates one of the frequent occurrences of sinus arrhythmia with wandering pacemaker. The Negative P-wave in this record suggests inverse depolarization from the atrioventricular node. Similar changes were observed before launch. (Recorder speed 25 mm/sec.)

Figure 25–2. MA–9. Sample of Biosensor Record at a Range Station.

appears to have little effect on physiologic response.

The in-flight medical results of the manned space flight missions through Gemini are summarized in the following paragraphs.

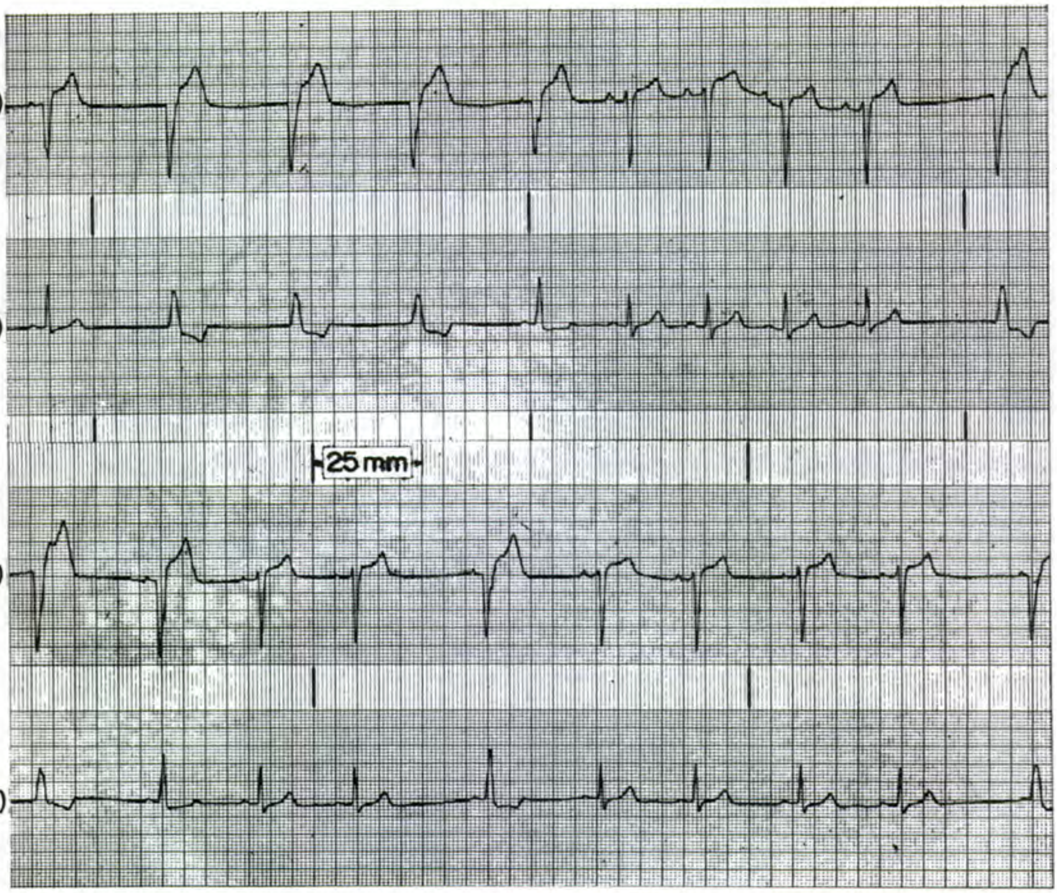
Central Nervous System

Psychological tests as distinct entities unrelated to in-flight tasks were not conducted. Instead, the high quality of performance on all missions served to described the adequacy of functioning of the central nervous system. This was illustrated during launch, rendezvous and docking, extravehicular activities, and the many accurate landings and recoveries. There was no evidence, either inflight or postflight, of any psychological abnormalities.

The EEG was used to evaluate sleep during the 14-day mission. A total of 54 hours and 43 minutes of interpretable EEG data was obtained. Variations in the depth of sleep from Stage 1 to the deep sleep in Stage 4 were noted in both in-flight and ground-based data.

Numerous observations reported by the crews involved in-flight sightings and descriptions of ground views. The actual determination of visual acuity was made in flight as well as in preflight and postflight examinations. All of these tests have supported the statement that *vision is not adversely affected during weightless flight.*

As previously noted, there had been much conjecture concerning vestibular changes in a weightless environment. In contrast to the data reported by the Russians, no evidence of altered vestibular function in flight was observed. Preflight and postflight caloric vestibular function studies and special studies of the otolith response revealed no significant changes. There were ample motions of the head in flight and during roll rates with the spacecraft, but there was never any vertigo or disorientation noted, even during the extravehicular activity when there was an occasional loss of all visual references. Several crewmen reported a feeling of fullness in the head similar in character to the fullness experienced when one



Recorder speed 25 mm/sec.

Figure 25–3. MA–9. Sample Record Illustrating Nodal Beats Occurring During Cancelled Launch Countdown.

is turned upside down. It is probable that this sensation resulted from altered distribution of blood in the weightless state. The lack of in-flight vestibular symptoms is interesting in view of the fact that a number of astronauts developed motion sickness while in the spacecraft on the water.

Skin

In spite of the moisture attendant to space suit operations, the skin remained in remarkably good condition through 14 days of space flight. Following the 8-day flight, some drying of the skin was noted during the immediate postflight period, but this was easily treated with lotion. There were no infections and there was only minimal reaction around the sensor sites. Dandruff was an occasional problem, easily controlled with preflight and postflight medication.

Eye, Ear, Nose and Throat

Two in-flight incidents of rather severe eye irritation occurred. One was the result of exposure to lithium hydroxide in the suit circuit. The other was not explained. In a few instances, a postflight conjunctival irritation which lasted only a few hours, was noted. The latter condition was attributed to the oxygen environment. Some nasal stuffiness occurred during the early portion of the flight, normally, the first 2 or 3 days. This nasal congestion was also related to the 100% oxygen environment and was usually self-limited. On occasion, the condition was treated locally or by oral medication.

The Respiratory System

Preflight and postflight X-rays failed to reveal any atelectasis. Pulmonary function studies before and after the 14-day mission revealed no alteration. Although no specific difficulties or symptomatology involving the respiratory system were evident, some rather high respiratory rates during heavy work loads in the extravehicular activity were present. Respiratory rates during all of the long-duration missions tended to vary normally, along with heart rate. The hyperventilation syndrome did not occur in flight.

The Cardiovascular System

The cardiovascular system was the first of the major body systems to show physiologic change following flight. Peak heart rates were observed at launch and at reentry, normally reaching higher levels during the reentry period. The midportions of all missions were characterized by more stable heart rates at lower levels with adequate response to physical demands.

Electrocardiograms were studied in detail throughout all missions. The only abnormalities of note during the Gemini program were very rare, premature auricular and ventricular contractions. There were no significant changes in the duration of specific segments of the electrocardiogram.

The only truly remarkable thing in all blood pressures, to date, has been the lack of significant increase or decrease with prolonged space flight. Blood pressure data obtained in the Gemini program showed that systolic and diastolic values remained within the envelope of normality throughout 14 days of space flight.

Cardiac cycle data were derived through synchronous phonocardiographic and electrocardiographic monitoring. Wide fluctuations in the duration of the cardiac cycle, but within physiological limits, were observed throughout these missions. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were observed for electromechanical delay (onset of QRS to onset of first heart sound) throughout the missions, with shorter values observed during the intervals of peak heart rates recorded during lift-off, reentry, and extravehicular activity. The higher values observed for the duration of systole and for electromechanical delay in certain astronauts suggest a preponderance of cholinergic influences (vagal tone). An increase in sympathetic tone (adrenergic reaction) was generally observed during lift-off, reentry, and in the few hours preceding reentry.

In Mercury, postflight tilt tests demonstrated the presence of moderate orthostatic hypotension, with far greater heart rates required to maintain effective cardiovascular function (see figures 25-4 and 25-5). Compensation was achieved, however, and the pilot did not develop even near-syncope. Contributing stress factors, including heat, the effect of prolonged confinement, dehydration, fatigue, and a possible effect of weightlessness *per se*, are thought to be the principal elements responsible for this change.

In contrast, orthostatism resulting from any Gemini mission was detectable only by means of passive tilt-table provocation (see figure 25-6). Tilt-table procedures were monitored with electronic equipment providing automatic monitoring of blood pressure, electrocardiogram, heart rate, and respiration. The procedure consisted of placing the crewman in a horizontal position for 5 minutes for stabilization, tilting to the 70° head-up position for 15 minutes, and then returning to the horizontal position for another 5 minutes. In addition to the usual blood pressure and pulse rate determinations at minute intervals, some mercury strain gages were used to measure changes in the circumference of the calf. On the 4-day, 8-day, and 14-day missions, no symptoms of faintness were experienced by the crew at any time during the landing sequence or during the post-landing operation. There was no increase in the time necessary to return to the normal preflight tilt response (a 50-hour period), regardless of the duration of the flight. The strain-gage data gen-

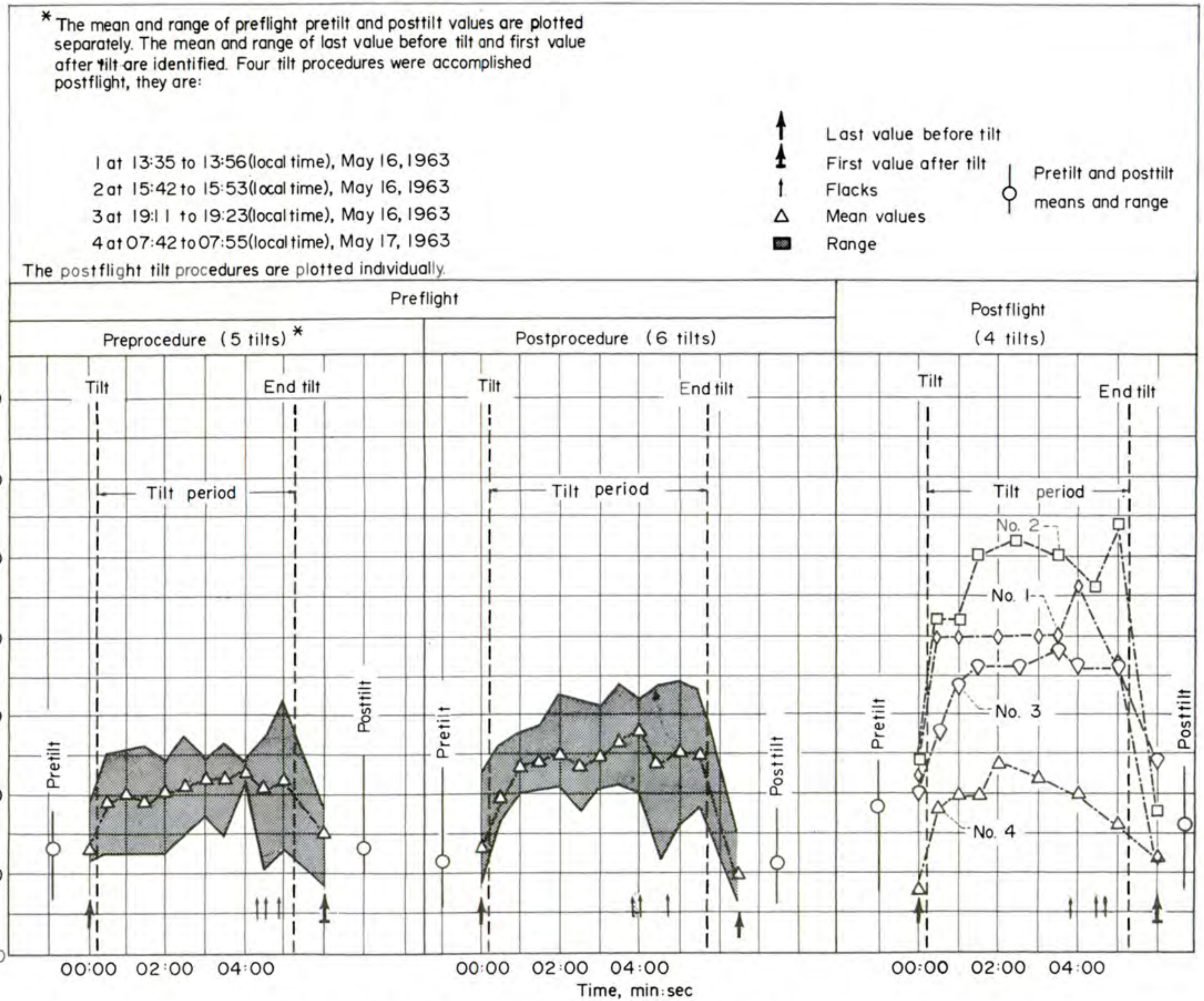


Figure 25–4. MA–9. Tilt Studies, Heart Rate Responses.

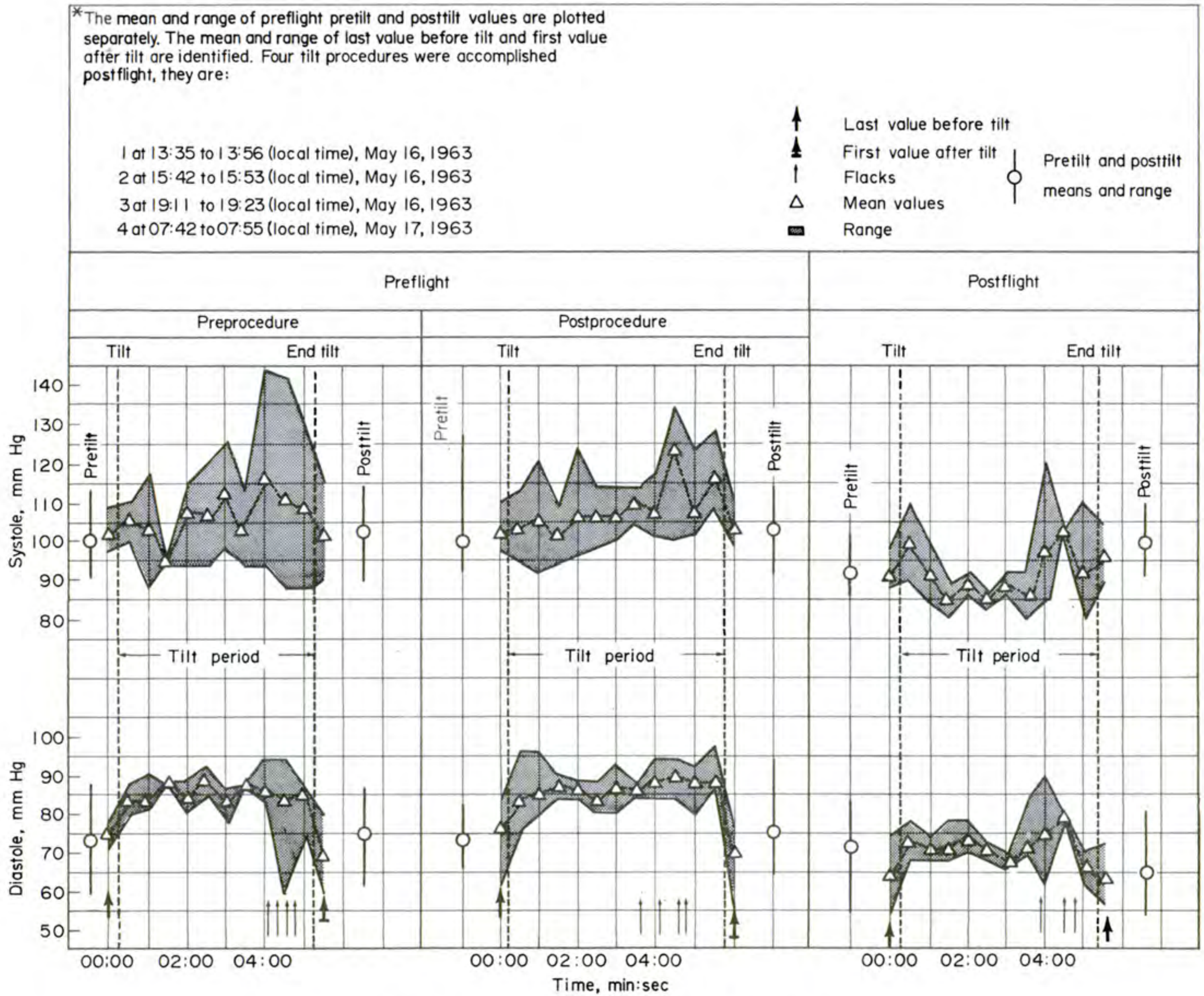


Figure 25–5. MA–9. Blood Pressure Responses.

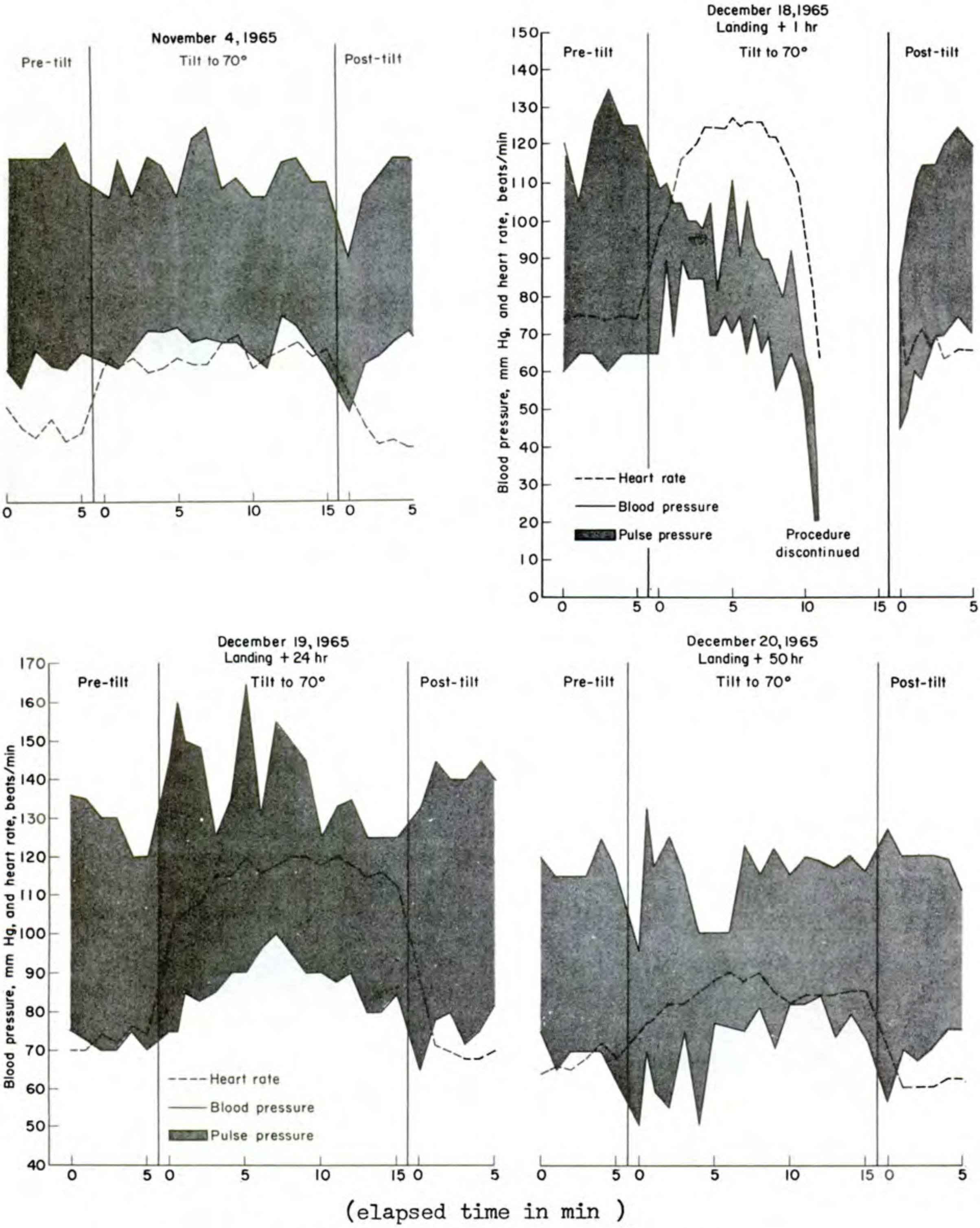


Figure 25–6. Tilt-Table Studies of Gemini 7 Pilot.

erally confirmed pooling of blood in the lower extremities during the period of, roughly, 50 hours that was required to readjust to the 1 G environment.

Blood Volume

On each of the long-duration flights, plasma volume was determined by the use of a technique using radioiodinated serum albumin. On the 4-day mission, red-cell mass was calculated by using the hematocrit determination. Analysis of the data caused some concern as to the validity of the hematocrit in view of the dehydration noted. The 4-day mission data showed a 7% and a 15% decrease in the circulating blood volume for the two crewmembers, a 13% decrease in plasma volume, and an indication of a 12% and a 13% decrease in red-cell mass, although it had not been directly measured. As a result of these findings, red cells were tagged with chromium 51 on the 8-day mission to get an accurate measurement of red-cell mass while continuing to use the radioiodinated serum albumin technique for plasma volume. The chromium-tagged red cells also provided a measure of red-cell survival time. At the completion of the 8-day mission, there was a 13% decrease in blood volume, a 4% to 8% decrease in plasma volume, and a 20% decrease in red-cell mass. These findings pointed to the possibility that the red-cell mass decrease might be incremental with the duration of exposure of the space flight environment. The 14-day flight results showed no change in the blood volume, a 4% and a 15% increase in plasma volume, and a 7% and a 19% decrease in red-cell mass for the two crewmembers. In addition, the red-cell survival time was reduced. These results are summarized in figures 25–7 and 25–8. It can be concluded that the decrease in red-cell mass is not incremental with increased exposure to the space flight environment. On the 14-day flight, the maintenance of total blood volume, by increasing plasma volume, and a weight loss noted, indicated that some fluid loss occurred in the extracellular compartment, but that the loss had been replaced by fluid intake after the flight. The loss of red cells had not interfered with normal function and was generally equivalent to the blood withdrawn in a blood bank donation, but the decrease occurred for a longer time, thus allowing for adjustment.

The detailed explanation of the decreased mass is unknown at the present time, but

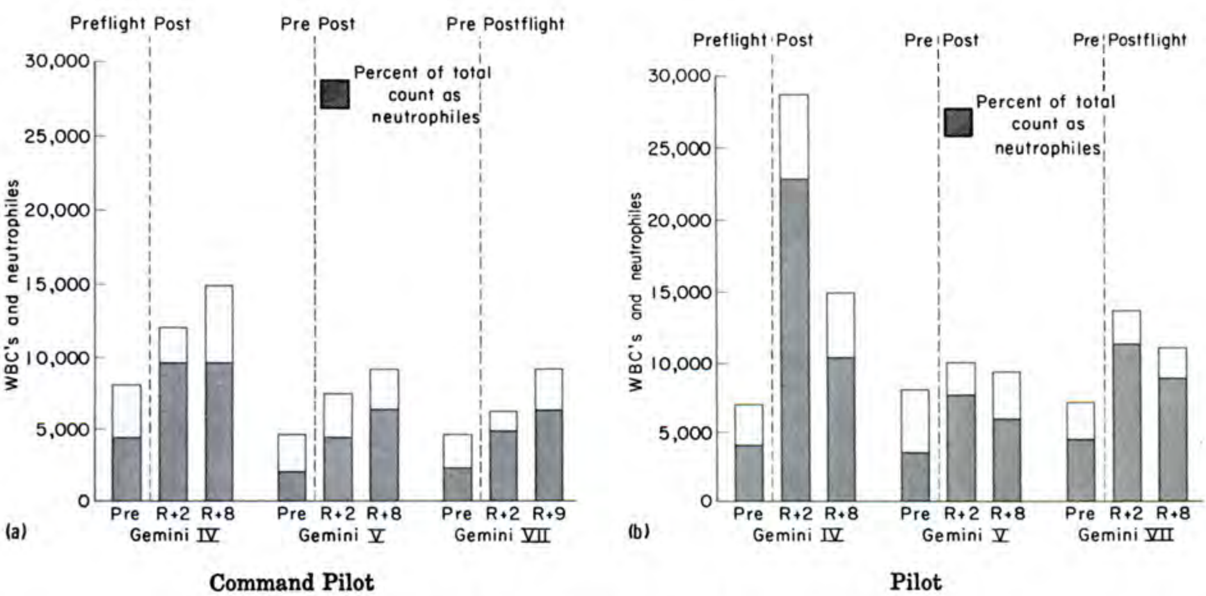


Figure 25–7. White Blood Cell Response.

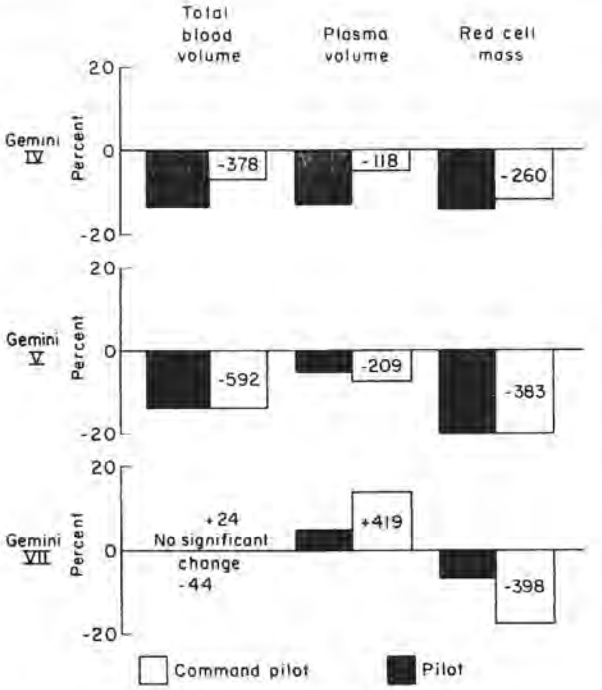


Figure 25–8. Blood Volume Studies.

several factors may underlie the red cell destruction. The variables which must be considered as possible causative factors are hyperoxia (*i.e.,* 166 mm O_2 at the alveolar membrane), lack of inert diluent gas (*i.e.,* nitrogen), relative immobility of the crew, dietary factors, and weightlessness. Of the factors stated, only increased oxygen tension, immobility and dietary factors are well known to influence the erythron. Dietary considerations may be of considerable importance, but no definite incriminations can be levied against the flight diet at this point. Immobility is effective in reducing red-cell mass by curtailing erythrocyte production; however, all flight observations support hemolysis as the significant event. Although not demonstrated by any previous studies, it is possible that weightlessness is a contributing factor in the hemolysis observed. Altered hemodynamics, resulting in hemostasis, could inflict a pre-lytic lesion on the erythrocytes involved and thereby result in the cell's premature demise. The role of a diluent gas (nitrogen) is not well understood; however, there has been shown a significant reduction in hematologic and neurologic toxicity in animals exposed to high pO_2 when an "inert" gas is present. Therefore, the absence of an "inert" atmospheric diluent could be significant at the hyperoxic levels encountered within the Gemini spacecraft.

Of all the mechanisms stated, oxygen has the greatest proven potential as a hemolytic agent. It has several documented deleterious effects on red-cell plasma membranes and metabolic functions, any combination of which could be operative within a Gemini spacecraft.

Biochemical Aspects

The analysis of urine and plasma has been used as an indication of astronaut physiological status preflight, in-flight, and postflight. Analyses of the results obtained in all three phases of the 14-day Gemini 7 flight were performed (see tables 25–7 and 25–8).

As expected, since a prime function of the homeostatic mechanisms of the body is to maintain the composition of blood and extracellular fluid as nearly constant as possible, significant changes in plasma were not observed. Pooled samples of flight urine indicated a slight reduction in the output of sodium during flight. This was associated with some increase in aldosterone excretion. Postflight, there was a marked retention of sodium. Chloride excretion paralleled the sodium excretion, and potassium excretion during flight appeared depressed and, in all but one instance, was depressed immediately postflight. This depression was observed in both the total 24-hour output and the minute output. The antidiuretic hormone appeared elevated in only the first postflight sample of the Gemini 7 pilot.

Calcium, magnesium, phosphate, and hydroxyproline were measured in plasma and in urine obtained preflight, in-flight, and postflight, as a continuing evaluation of the effects of space flight on bone demineralization. Following the 14-day flight, postflight plasma samples showed a marked increase in the bound hydroxyproline, while larger quantities of calcium were excreted later in the

TABLE 25-7. GEMINI 7 COMMAND PILOT PLASMA ANALYSIS (1965)

Components	Preflight		Postflight			
	Nov. 25	Dec. 2	Dec. 18 (1130 hr)	Dec. 18 (1820 hr)	Dec. 19	Dec. 21
Sodium, meq/liter	147	146	138	140	144	143
Potassium, meq/liter	4. 7	5. 4	4. 1	4. 7	4. 7	4. 9
Chlorine, meq/liter	103	103	100	102	103	106
Phosphate, mg, percent	3. 2	3. 7	4. 0	4. 2	3. 1	3. 6
Calcium, mg, percent	9. 0	9. 2	8. 6	9. 2	9. 0	9. 2
Urea nitrogen, mg, percent	19	16	16	20	25	18
Uric acid, mg, percent	6. 8	6. 6	4. 6	6. 0	5. 9	6. 0
Total protein, g, percent	7. 3	7. 4	6. 8	7. 6	7. 0	7. 1
Albumin, g, percent	4. 7	4. 9	4. 2	QNS	4. 5	4. 6
17-OH corticosteroids, micrograms per 100 ml	18. 8	----------	28. 3	16. 0	----------	----------
Hydroxyproline, micromilligrams per ml:						
Free	. 008	. 007	. 010	. 011	----------	----------
Bound	. 131	. 146	1. 51	. 185	----------	----------
Total	. 139	. 153	. 161	. 196	----------	----------

TABLE 25-8. GEMINI 7 COMMAND PILOT URINALYSIS (1965)

Components	Preflight		Postflight	
	Nov. 23	Dec. 1	Dec. 18	Dec. 21
Chlorine, meq	144	148	61	145
Calcium, mg	254	266	310	268
Uric acid, g	. 96	. 95	1. 20	1. 07
Total volume, ml	2920	3235	2160	3690
Sodium, meq	141	146	64	133
Potassium, meq	93. 0	79	73	106
Phosphate, g	1. 13	1. 16	1. 72	1. 12
17-hydroxycorticosteroids	6. 9	8. 76	13. 69	9. 28
Total nitrogen, g	19. 2	22. 6	30. 9	20. 5
Urea nitrogen, g	18. 1	18. 5	26. 6	18. 7
Hydroxyproline, mg	48. 74	37. 0	65. 4	39. 9
Creatinine, g	2. 11	2. 11	2. 86	1. 80

flight than during the early phases of the flight, findings consistent with a change in bone structure.

Gastrointestinal System

The design and fabrication of foods for consumption during space flights imposed unique technological considerations. The volume of space food per man-day varied in the Gemini mission from 130 to 162 cubic inches (2131 cc to 2656 cc). Menus were made up of approximately 50 to 60% rehydratables (foods requiring the addition of water prior to ingestion), requiring food-packaging permitting both a method for rehydration and dispensing of food in zero G. The remaining foods were bite-size. About 50% of both the rehydratable and bite-size foods were freeze-dried products; the remaining were other types of dried or low-moisture foods, some of which were compressed. A typical menu had an approximate calorie distribution of 17% protein, 32% fat and 51% carbohydrate. Total calories provided and eaten per day varied from flight to flight. Although weight loss occurred on all missions, the amount of weight loss did not increase with mission duration.

Gastrointestinal-tract function on all missions was normal and there was no evidence of excess nutrient losses due to poor food digestibility during flight. Before the missions, the crews ate a low-residue diet and, in addition, on all flights, beginning with the Gemini 5 mission, oral and suppository laxatives were used during the last 2 days before flight. Figure 25–9 illustrates the in-flight defecation frequency. On the shorter EVA missions, crew preparation generally allowed them to avoid defecation in flight.

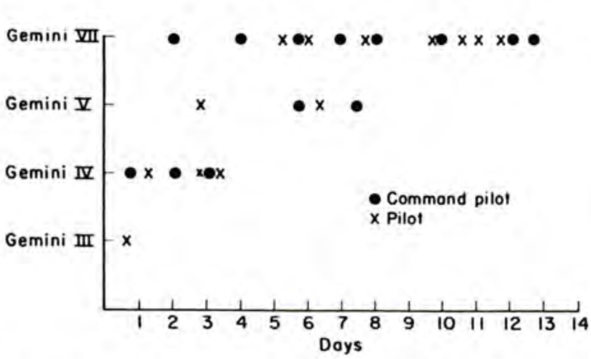


Figure 25–9. In-Flight Defecation Frequency.

Genitourinary System

Difficulties involving the genitourinary system were not encountered during any of the missions. Urination occurred normally, both in-flight and postflight, and there was no evidence of renal calculi (see figure 25–10).

Musculoskeletal System

To date, the information available on bone and muscle metabolism as affected by space flight is limited to a very few subjects under varying dietary intakes and multiple flight stresses.

The bone demineralization (percent change in density) which occurred in the os calcis and phalanx 5-2 during the 14-day flight and under equivalent periods of bed rest with analogous intake of calcium, was definitely less in the 14-day flight, where calcium intake approached 1,000 mgs per day and the crew exercised routinely (see table 25–9). In all instances, the data on the bones examined indicates a negative change, and the

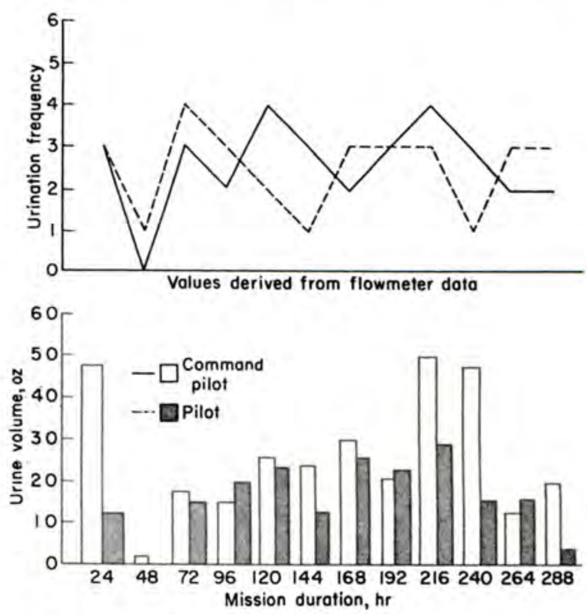


Figure 25–10. Urine Volume and Urination Frequency of Gemini 7 Flight Crew.

TABLE 25-9. COMPARISON OF BONE DENSITY CHANGES IN GEMINI 7 CREW WITH BEDREST SUBJECTS ON SIMILAR DIETS FOR 14 DAYS

	Gemini VII crew		TWU bedrest subjects
	Command pilot	Pilot	
Mean calcium daily intake (estimated), grams	1.00	1.00	(1) 0.931 (2) 1.021 (3) 1.034 (4) 1.020 (5) 0.930
Change in conventional section of os calcis in bone mass (calibration wedge equivalency), percent	−2.91	−2.84	(1) −3.46 (2) −3.56 (3) −5.79 (4) −5.11 (5) −5.86
Change in bone mass of hand phalanx 5-2, percent	−6.78	−7.83	(1) −1.57 (2) −1.00 (3) −0.44 (4) −0.96 (5) −1.27

calcium-balance data collected on Gemini 7 verifies a negative-balance trend. None of the changes is pathological, but they do indicate that ameliorative methods for use during flights of longer duration need to be examined.

It is interesting to note the differences in bone-mass change occurring in the several flights (see table 25-10). It is probable that the superior findings in the os calcis during the 14-day Gemini 7 flight could be attributed to a number of factors, among them the following: the crewmembers of this mission ate a far higher proportion of the diet prepared for them than did those of Gemini 4 and Gemini 5; had isometric and isotonic exercises daily for prespecified periods of time; used an exerciser routinely; and slept for longer periods of time.

Medication

Medications in both injectable and tablet form were routinely provided on all flights. The basic policy has continued to be that drugs are to be used only if necessary. A list of the supplied drugs is shown in table 25-11. The injectors may be used through the suit, although, to date, none has been utilized. Various drugs were used for symptomatic treatment of minor complaints, but the only significant medication used was d-amphetamine, taken prior to reentry by the Gemini 4 crew. This drug was taken to insure an adequate state of alertness during the critical mission period. In spite of the minimal use of medications, they must be available on long-duration missions, and each crewmember must be pretested with any drug that may be used. Pretesting of all of the medications listed was carried out on each of the crews.

The medical results of the United States manned space flight efforts have been gratifying. Not only has new knowledge been acquired, but this knowledge has, in turn, generated confidence and assurance in the role of man in Apollo and future space exploration programs.

Crewmembers experienced no disorientation on any Gemini mission. The crews adjusted very easily to the weightless environ-

TABLE 25-10. COMPARISON OF BONE DENSITY CHANGES IN CREWMEN OF GEMINI 4, GEMINI 5, AND GEMINI 7 DURING SPACE FLIGHT

Position of anatomical site evaluated	Change in bone mass,[a] percent	
	Command pilot	Pilot
Conventional os calcis scan:		
Gemini IV	−7.80	−10.27
Gemini V	−15.10	−8.90
Gemini VII	−2.91	−2.84
Multiple os calcis scans:		
Gemini IV	−6.82	−9.25
Gemini V	−10.31	−8.90
Gemini VII	−2.46	−2.54
Hand phalanx 5–2 scans:		
Gemini IV	−11.85	−6.24
Gemini V	−23.20	−16.97
Gemini VII	−6.78	−7.83
Hand phalanx 4–2 scans:		
Gemini IV	([b])	([b])
Gemini V	−9.98	−11.37
Gemini VII	−6.55	−3.82

[a] Based on X-ray absorbency of calibration wedge.
[b] Not done on this flight.

ment and accepted readily the fact that objects will stay in position in midair or will float. There was no difficulty in reaching various switches or other items in the spacecraft. The crewmen moved their heads at will and noticed no aberrant sensations. They were always oriented to the interior of the spacecraft and could orient themselves in relation to the earth by rolling the spacecraft and finding the horizon through the window. During the extravehicular operations, the pilot oriented himself by his relationship to the spacecraft in all of the maneuvers. Looking repeatedly at the sky and the earth, he had no sensations of disorientation or motion sickness. The venting of hydrogen on the 8-day flight created some roll rates of the spacecraft that became of such magnitude that the crew preferred to cover the windows to stop the visual irritation of the rolling horizon, thus allowing them to wait a longer time before damping the rates with thruster activity. During the 14-day flight, the crew repeatedly moved their heads in various directions to try to create disorientation, but to no avail. They also had tumble rates of 7° to 8° per second, created by venting from the water boiler; one time, they performed a spin-dry maneuver to empty the water boiler, which created roll rates of 10° per second. On both occasions, they moved their heads freely and had no sensation of disorientation.

The crews of all three long-duration missions noted an increased G-sensitivity at the time of retrofire and reentry. All felt that they were experiencing several Gs when the G-meter was just beginning to register at reentry. However, when the peak G-load was reached, their sensations did not differ from their centrifuge experience.

The crews described a sensation of fullness in the head that occurred during the first 24 hours of the mission and then gradually disappeared. This feeling was similar to the increase of blood a person notes when hanging on parallel bars or when standing on his head. There was no pulsatile sensation in the head and no obvious reddening of the skin. The exact cause of this condition is unknown, but it may be related to an increase of blood in the chest area as a result of the readjustment of the circulation to the weightless state.

An early problem of concern was the question of the ability of the crewmembers to get along with one another for the long flight periods. Every effort was made to choose crewmembers who were compatible. It is truly remarkable that none of the crews, including the long-duration crews, had any in-flight psychological difficulties that were evident to the ground monitors or that were discussed in postflight debriefings. They had some normal concerns for the inherent risks of space flight. There was some expected increased tension at lift-off and prior to retrorocket firing; also, a normal psychological letdown when the Gemini 7 crew saw the Gemini 6A spacecraft depart after their rendezvous. However, the Gemini 7 crew ac-

TABLE 25-11. GEMINI 7 IN-FLIGHT MEDICAL AND ACCESSORY KITS

(a) Medical kit

Medication	Dose and form	Label	Quantity
Cyclizine HCl	50-mg tablets	Motion sickness	8
d-Amphetamine sulfate	5-mg tablets	Stimulant	8
APC (aspirin, phenacetin, and caffeine)	Tablets	APC	16
Meperidine HCl	100-mg tablets	Pain	4
Triprolidine HCl	2.5-mg tablets	Decongestant	16
Pseudoephedrine HCl	60-mg tablets		
Diphenoxylate HCl	2.5-mg tablets	Diarrhea	16
Atropine sulfate	0.25-mg tablets		
Tetracycline HCl	250-mg film-coated tablet	Antibiotic	16
Methylcellulose solution	15-cc in squeeze-dropper bottle	Eyedrops	1
Parenteral cyclizine	45-mg (0.9-cc in injector)	Motion sickness	2
Parenteral meperidine HCl	90-mg (0.9-cc in injector)	Pain	2

(b) Accessory kit

Item	Quantity
Skin cream (15-cc squeeze bottle)	2
Electrode paste (15-cc squeeze bottle)	1
Adhesive disks for sensors	12 for EKG, 3 for phonocardiogram leads
Adhesive tape	20 in.

TABLE 25-12. RADIATION DOSAGE ON GEMINI LONG-DURATION MISSIONS (IN MILLIRADS)

Mission	Command pilot	Pilot
Gemini IV [a]	38.5 ± 4.5	42.5 ± 4.7
	40.0 ± 4.2	45.7 ± 4.6
	42.5 ± 4.5	42.5 ± 4.5
	45.0 ± 4.5	69.3 ± 3.8
Gemini V [a]	190 ± 19	140 ± 14
	173 ± 17.3	172 ± 17.2
	183 ± 18.3	186 ± 18.6
	195 ± 19.5	172 ± 17.2
Gemini VII [b]	178 ± 10	98.8 ± 10
	105 ± 10	215 ± 15
	163 ± 10	151 ± 10

[a] Values are listed in sequence: left chest, right chest, thigh, and helmet.

[b] Values are listed in sequence: left chest, right chest, and thigh.

cepted this very well and immediately adjusted to the flight-plan activity.

From a medical point of view, over-all crew performance was exemplary during all flights. There was no decrease in performance noted, and the fine control tasks, such as reentry and, notably, the 11th-day rendezvous during the Gemini 7 mission, were handled with skill.

The long-duration flights confirmed previous observations that the flight crews were exposed to very low radiation-dose levels at orbital altitudes. The body dosimeters on these missions recorded only millirad doses which were at an insignificant level. The recorded doses are shown in table 25-12.

REFERENCES

The reader should insure the currency of listed references.

Armstrong, H. G., *Origin of Space Medicine,* US Armed Forces Medical Journal 10: 389–440 (1959).

Armstrong, H. G., *Aerospace Medicine,* Chapter 31, "Space Medicine," The Williams and Wilkins Co., Baltimore, Md. (1961).

Benson, O. O., Jr. and Strughold, H., Editors: *Physics and Medicine of the Atmosphere and Space,* John Wiley & Sons, Inc., New York (1960).

Berry, Charles A., *Man's Response to a New Environment, Including Weightlessness: Gemini Biomedical Results.* (Paper presented before the International Astronautical Federation Congress, Madrid, Spain, October 9-15, 1966.)

Caiden, M. and C., *Aviation and Space Medicine,* Dutton, New York (1962).

Campbell, P., Editor: *Energies of Space,* Columbia University Press, New York (1961).

Conference on Nutrition in Space and Related Waste Problems, April 27-30, 1964, SP–70, US Government Printing Office, Washington, DC.

Flaherty, R. E., *Psychophysiological Aspects of Space Flight,* Columbia University Press, New York (1961).

Fraser, T. M., *The Effects of Confinement on Man,* US Government Printing Office, Washington, DC (July 1965).

Fraser, T. M., *Human Response to Sustained Acceleration,* NASA–SP–103, US Government Printing Office, Washington, DC (1964).

Fraser, T. M., *Philosophy of Simulation in a Man-Machine Space Mission System,* NASA–SP–106, US Government Printing Office, Washington, DC (August 1965).

Fraser, T. M., *Biomedical Techniques for Use on Manned Space Laboratories, Part I,* "Parameters, Cardiac Output, Blood Pressure, Cardiac Kinetics" (January 1966). (Unpublished NASA report.)

Fraser, T. M., *Biomedical Techniques for Use on Manned Space Laboratories, Part II,* "Respiratory Physiology" (April 1966). (Unpublished NASA report.)

Fraser, T. M., *The Storage of Biological Samples* (March 1966). (Unpublished NASA report.)

Haber, H., *The Physical Environment of the Flyer,* School of Aviation Medicine, USAF, Randolph Air Force Base, Texas (1954).

Hanrahan, J. S. and Bushnell, D., *Space Biology,* Basic Books, New York (1960).

Lamb, L. E., *Medical Aspects of Interdynamic Adaptation in Space Flight,* Journal of Aviation Medicine 30:158–161 (1959).

Lansberg, M. P., *A Primer of Space Medicine,* Elsevier Pub., New York (1960).

Lectures in Aerospace Medicine: An annual Lecture Series published under sponsorship of USAF School of Aerospace Medicine, 1960, '61, '62, '63, and '64, Brooks Air Force Base, Texas.

Link, Mae M., *Space Medicine in Project Mercury,* NASA Report SP–4003, US Government Printing Office, Washington, DC (1965).

Roth, E. M., *Study of Aerospace and Environmental Medicine Information System* (AEMIS, Thesaurus) (April 1964). (Unpublished NASA report.)

Roth, E. M., *Review of Symposium on Protection Against Radiation Hazards in Space,* Gatlinburg, Tennessee, November 5-7, 1962 (unpublished).

Roth, E. M., *Space-Cabin Atmospheres, Part I,* "Oxygen Toxicity," NASA–SP–47, US Government Printing Office, Washington, DC (June 1963).

Roth, E. M., *Space-Cabin Atmospheres, Part II,* "Fire and Blast Hazards," NASA–SP–48, US Government Printing Office, Washington, DC (October 1963).

Roth, E. M., *Space-Cabin Atmospheres, Part III,* "Physiological Factors of Inert Gases," NASA–SP, US Government Printing Office, Washington, DC (1965).

Roth, E. M., *Space-Cabin Atmospheres, Part IV,* "Engineering Trade-Offs of One Versus Two-Gas Systems" (1966). (NASA report in press.)

Roth, E. M., *Bioenergetic Considerations in the Design of Space Suits for Lunar Exploration,* NASA-SP-84, US Government Printing Office, Washington, DC (1963).

Roth, E. M., *Information Source Report, Toxicity of Rocket Fuels* (August 1963). (Unpublished NASA report.)

Roth, E. M., *Space-Cabin Atmospheres, NASA Conference on Peaceful Uses of Space* (April 1964). (Unpublished NASA report.)

Roth, E. M., *Gas Physiology in Space Operations,* New England Journal of Medicine 275:144-154, 196-203, 255-263 (July 21, 28, and August 4, 1966).

Roth, E. M., *Use of Animals in Man-Rating Space-Cabin Simulators* (October 1964). (Unpublished.)

Roth, E. M., *Physiological Uses of Inert Gases Other Than Nitrogen* (paper presented at AIAA/ASMA meeting, St. Louis, Mo., October 1965).

Sells, S. B. and Berry, C. A., *Human Factors in Jet and Space Travel,* Ronald Press, New York (1961).

Simons, D. G., *The "Manhigh" Sealed Cabin Atmosphere,* Journal of Aviation Medicine 30:314-325 (1959).

Slager, Ursala T., *Space Medicine,* Prentice-Hall, New Jersey (1967).

Strughold, H., *Space Equivalent Conditions Within the Earth's Atmosphere,* Astrobica Acts, Sprinter Verlag, Vienna (1955).

Strughold, H., *The Green and Red Planet,* University of New Mexico Press, Albuquerque, New Mexico (1953).

Strughold, H. and Ritter, O. L., *Solar Irradiance from Mercury to Pluto,* Journal of Aerospace Medicine, Volume 31, Pgs 127-130 (1960).

Strughold, H., Haber, H., Buettner, K., and Haber, F., *Where Does Space Begin?,* Journal of Aviation Medicine 22:342-49 (1951).

Vinograd, S. P., Editor, *Medical Aspects of an Orbiting Research Laboratory,* Space Medicine Advisory Group Study, SP-86, US Government Printing Office, Washington, DC (1966).

Webb, Paul, Editor, *Bioastronautics Data Book,* SP-3006, US Government Printing Office, Washington, DC (1964).

White, C. S. and Benson, O. O., Editors: *Physics and Medicine of the Upper Atmosphere,* University of New Mexico Press, Albuquerque, New Mexico (1952).

Staff of NASA Manned Spacecraft Center: *Results of the First U. S. Suborbital Space Flight,* June 6, 1961, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Results of the Second United States Manned Suborbital Space Flight,* July 21, 1961, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Results of the First United States Manned Orbital Space Flight,* February 20, 1962, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Results of the Second United States Manned Orbital Space Flight,* May 24, 1962, SP-6, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Results of the Third United States Manned Orbital Space Flight,* October 3, 1962, SP-12, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Results of the Project Mercury Ballistic and Orbital Chimpanzee Flights,* SP-39, US Government Printing Office, Washingtion, DC (1963).

Staff of NASA Manned Spacecraft Center: *Mercury Project Summary,* May 15-16, 1963, SP-45, US Government Printing Office, Washington, DC.

Staff of NASA Manned Spacecraft Center: *Gemini Mid-Program Conference,* February 23-25, 1966, SP-121, US Government Printing Office, Washington, DC.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

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Chief of Staff

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Director of Administrative Services

Summary of Revised, Deleted, or Added Material

This pamphlet contains major revisions of chapters from the Flight Surgeon's Manual pertaining to the following: Aerospace Medicine Program (chap 1); Effects of Decreased Partial Pressure of Oxygen, Decreased Barometric Pressure, Accelerative Forces, and Temperature (chaps 2 thru 5); Otolaryngologic Aspects—Barometric Pressure Changes (chap 6); Noise, Problems of the Eye, Psychiatric Disorders, Dental Problems, Drugs, Fatigue, and Nutrition (chaps 7 thru 13); Aviation Pathology, Aircraft Accident Prevention and Investigation, Emergency Egress, and Rescue and Recovery (chaps 14 thru 17); Pressure Suits (chap 18); Aeromedical Evacuation (chap 19); Military Public Health and Occupational Medicine (chaps 20 and 21); Water Control (chap 22); Control of Arthropods and Rodents (chap 23); Disaster Preparedness for Nuclear, Biological and Chemical Operations (chap 24); Space Medicine (chap 25). It does not contain the following topics from the Flight Surgeon's Manual: Epidemiology; Specific Diseases; Immunizations; Aircraft, Field and Food Service Sanitation; Medical Service Organization, Personnel, Research, Intelligence, Materiel, Treatment Facilities, Training, and Administrative and Operational Procedures.

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