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AVIATION MEDICINE

AND

PSYCHOLOGY

A Report of the AAF Scientific Advisory Group

by

W. R. LOVELACE, II

A. P. GAGGE, Lt. Col. A.C.

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Aviation MEDICINE AND PSYCHOLOGY

A REPORT PREPARED FOR THE AAF SCIENTIFIC ADVISORY GROUP

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The AAF Scientific Advisory Group was activated late in 1944 by General of the Army H. H. Arnold. He secured the services of Dr. Theodore von Karman, renowned scientist and consultant in aeronautics, who agreed to organize and direct the group.

Dr. von Karman gathered about him a group of American scientists from every field of research having a bearing on air power. These men then analyzed important developments in the basic sciences, both here and abroad, and attempted to evaluate the effects of their application to air power.

This volume is one of a group of reports made to the Army Air Forces by the Scientific Advisory Group.

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PART I

FUTURE TRENDS OF RESEARCH IN AVIATION MEDICINE

By

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and

A. P. GAGGE, COLONEL, A.C.

PREFACE

The province of aviation medicine extends from the initial selection of personnel for training to the consideration of human factors in the design of aircraft, equipment in the aircraft, personal equipment for the flyer and maintenance and survival of the flyer.

The present report and its appendices are devoted to an outline of future problems in aviation medicine and the importance of continued research on these problems for an interim air force capable of taking off, landing, and flying any place in the world independently of the weather.

It has been said that aircraft such as the Flying Fortress, the Superfortress and the Thunderbolt were not wartime developments but accelerated and culminated results of peacetime research. This was true to a very minor degree in the field of human engineering which was just beginning to be recognized as an important and essential field for research. Aircraft cockpits and airplane turrets were badly designed from the standpoint of the individual using them in flight, as well as from the standpoint of the occurrence of unnecessary injuries or death in event of a crash. Oxygen equipment was inadequate in performance, and only as a result of great strides just prior to the war was equipment available that was suitable for use. Even this equipment, because of inadequacies under combat conditions and in low temperature, was entirely replaced during the war.

In the present report, strong support is given to continued use of personnel and research facilities in order to maintain the sciences involved in human engineering on the level to which they have been rightfully raised by the exigencies of war. Much of the knowledge gained in such research will be of value in general physiology.

From a medical standpoint the catastrophic effect of a conventional 1000 airplane bombing raid on a large city is not fully appreciated by laymen. Within a very short time there are thousands of people killed and many more thousands with burns, blast injuries, crushing injuries, wounds from bomb fragments and fragments of material blown into them by the explosion, oxygen want and carbon monoxide poisoning. Medical service is extremely difficult because of destruction of hospitals and first aid stations, loss of medical personnel and supplies and disruption of transportation. When an atomic bomb is dropped the above problems occur instantaneously throughout instead of over a period of minutes. No region in the bombed area is spared and there are the additional factors of intense heat and light, more severe mechanical effects and intense radiation from neutrons and gamma rays.

Also of interest and importance from the medical standpoint of aerial warfare with Germany was the shift in vital statistics with regard to the cause of wounds and deaths beginning in 1943. In that year the ratio of deaths to wounded in the military forces was 1 to 5, but by 1944 and 1945 the ratio was 1 to 3, almost entirely as the result of aerial warfare. At this time bombing and strafing as the cause of wounds and deaths were far ahead of artillery while infrantry weapons were a poor third.

The authors wish to express their appreciation to Brig. General Eugene Reinartz, U.S.A., Commandant School of Aviation Medicine, Randolph Field, Texas, and Colonel Lloyd E. Griffis, M.C., Chief Research Division, Office of the Air Surgeon, Headquarters, AAF, for their cooperation in making their future research program and plan available for the preparation of the present report. They are also greatly indebted to Lt. Col. Mavis P. Kelsey, M.C., Major Loren D. Carson, A.C., and Captain Vernon Wulff, Staff Members of the Aero Medical Laboratory, Wright Field, for their aid in collecting and assembling the necessary data. Finally, they wish to thank Dr. Richard M. Hewitt, Publications Director, Mayo Clinic, Rochester, Minnesota, for his helpful editorial advice.

PART I

FUTURE TRENDS OF RESEARCH IN AVIATION MEDICINE

AERO MEDICAL RESEARCH TODAY AND TOMORROW

A SUMMARY AND REVIEW

With the entry of the United States into World War II, there existed great need for rapid design and production of efficient combat aircraft. Because of lack of fundamental research applied to human beings engaged in flying, aircraft were designed and produced in such a way as to take little recognition of those who were to operate them. As a result, aircrew members often were required to perform highly skilled jobs under conditions disadvantageous to human activity. As the war progressed, it became evident that it was the airman-aircraft complex which must be made into an efficient fighting element rather than the aircraft alone. This problem dictated three fundamental approaches: (1) a consideration of human requirements in the design of aircraft, which must include assessment of requirements in the light of human limitations as well as application of those requirements in equipment; (2) selection of aircrew members on the basis of those human qualities which make for efficient combat airmen; and (3) training of aircrew members in the technics which would enable them to survive and perform efficiently under the unusual stresses produced by high speed, high altitude and contact with the enemy. It is now realized that emphasis on human requirements in the design of aircraft will decrease proportionately the effort otherwise necessary to meet requirements for personal equipment, and concurrently will increase the efficiency of the flyer.

A comparison of development and operation in the enemy air force demonstrates that the German Air Force developed and operated several types of turbojet and rocketjet aircraft well in advance of similar developments by the Allied Air Forces. This accomplishment resulted from a high degree of coordination in all phases of their research program. The research program had been in effect for a for a long time and the value of engineering development was well known to the German Air Force. The development of high-speed aircraft introduced the problem of safety and German studies in this field were far ahead of those of the United States Army Air Forces, especially in development of the ejection seat and parachutes for use when bailing out at high speeds. Factors in escape from aircraft at high speed had been carefully studied. Aside from these outstanding developments, research and development by the United States Army Air Forces paralleled, and in many cases exceeded, corresponding studies of the German Air Force, such as in the development of pressure-breathing equipment, the g-suit and cabin pressurization of the B-29. There was some very good fundamental research on anoxia and centrifugal force carried out in Japan but the applied research in aviation medicine was far behind that of the United States Army Air Forces and also behind that of the Germans. There was considerable duplication of work between the services. In addition, Japanese service personnel usually did not tell civilian scientists about classified information thereby handicapping the civilian at the start when he was given a problem such as pressure breathing. For example, Japanese civilian scientists often did not know that the oxygen equipment used by their air force was inadequate at altitudes in excess of 30,000 ft and therefore studies on safety and pressure breathing were of vital importance.

The development of equipment, the requirements for which are laid down on the basis of research done in the field of aviation medicine, has strikingly advanced in the past four years. Advances made in the previous twenty-three years, since the termination of World War I, were not nearly as extensive or far reaching. In 1918 oxygen equipment available was an automatic, continuous-flow Dreyer apparatus, which was used with a pipe stem and weighed approximately 5 lb. In 1940, following a few abortive attempts to change from high-pressure oxygen systems to a liquid-oxygen system and following, once again, the return to high-pressure equipment, a manual continuous-flow regulator was in use, with a Type A-7 mask which had been taken over from clinical oxygen equipment. The apparatus weighed approximately 2 lb. In the major campaigns of the war, airmen used an automatic diluter demand type regulator and a demand mask, both of which were developed and produced in the course of the war. The termination of the war found the United States Army Air Forces in possession of pressure demand equipment which combined flow and pressure indicating instruments and raised the operating ceiling from 37,000 ft to 42,000 ft and, for emergencies, even to 50,000 ft.

Concurrent development in the field of clothing, size of cockpit and many other aviation medical problems can be cited to demonstrate that adequate solutions follow when scientific personnel and their assistants are provided with proper research facilities.

The steps in development and standardization of equipment, or in application to equipment of data concerning human requirements, require highly qualified personnel to supervise each and every step. Following the receipt of a requirement for equipment, Army Air Forces research specialists and technicians examine the requirements and compile from all available sources the data which have been collected and are applicable to the special equipment requirement. Existing data must be intelligently reviewed and a program of further research outlined if the data are found inadequate. Once basic requirements are on hand, available equipment is examined to determine whether an item exsits which meets the requirements or which can be modified to meet the requirements. If necessary, new equipment is designed in close cooperation with engineers representing various manufacturers. Single items are made for initial laboratory tests, to determine the shortcomings of the items tested. Redesign and tests of the basic model are continued until satisfactory items are attained. Then a sufficient number are made so that flight tests in specially designed aircraft, equipped with the necessary instruments, can be made. Following these tests, the equipment is sent to the Army Air Forces Board for standardization. During the war short cuts were necessarily introduced into this program of development of equipment to meet the exigency of the situation. Many times equipment was designed although adequate basic data were not available and the design tests and standardization of necessity were made on the basis of existing but incomplete data, with the intent of producing for immediate but temporary use an instrument which was superior to an existing piece of equipment. In order successfully to carry out applied research, some of the personnel in the Aero Medical Laboratory at Wright Field must be capable of or else have carried out basic research; otherwise it is impossible properly to evaluate design requirements for equipment used by human beings.

Further research in aviation medicine must be coupled with future design of aircraft. The Army Air Forces soon will have available improved cargo aircraft, turbojet fighters, turbojet bombers, short-range rocket aircraft and guided missiles. The crew compartments of these aircraft will be pressurized and the extent of pressurization will be limited by the considerations imposed by the human beings who pilot the aircraft. In addition, high-speed, high-altitude reconnaissance aircraft and cargo and troop-transport aircraft will be necessities.

In the more distant future, major consideration will be the long-range rocketjet aircraft which may be piloted or pilotless. The pilotless type may be ground-launched or launched from the air. For those rocketjet aircraft which are launched from the air, parent aircraft must be supplied.

Projected designs for aircraft will bring about excessive demands on personnel due to altitude and speed. Although the aircraft will be designed with adequate pressure cabins to protect personnel, continuing research on human requirements will be necessitated by emergency conditions that arise in combat or from accidental failure of equipment.

For continued flight above 35,000 ft, cabin pressurization, more than added oxygen and added caution, are required to protect the flying personnel because of their increasing susceptibility to aeroembolism. Above 42,000 ft cabin pressuization combined with an emergency pressure demand oxygen system is adequate. Above 50,000 ft all existing oxygen equipment is inadequate.

Supersonic speeds of future aircraft will add requirements beyond the existing protection from g effect. Present g suits will protect personnel at 7 g for 10 sec. The suit can be improved, which is becoming increasingly difficult, or the position of the pilot changed. The exact relationship of human tolerance to short durations of g has not been adequately evaluated. The problems involved in vision at high speed, both from the standpoint of cockpit canopies and protective glasses or goggles will involve extensive development. Sun glasses and goggles need to be shatter proof and give as much flak protection to the eyes as possible. The effect on color vision of different colored sun glasses has not been determined finally. Personnel watching or exposed to the explosion of atomic bombs or missiles must wear lenses to protect them from the intense light. Correction factors ground in the lenses enable the experienced flyer with deficient vision to carry out his flying duties in a normal manner. Further studies on the effect of watching radar and television screens for long periods of time will be productive. The problems of controlling aircraft operating at high speed and of correlating hand and foot control with visual stimulus are of intense interest and practical value. Escape from high-speed aircraft not only entails study of human factors which are related to the ejection seat but, also, it requires that attention be given to the problems presented by parachute-opening shock and by exposure to high altitude, high wind velocity and extreme cold for short and long periods of time. The excessive demands which may be placed on human beings by the phenomenon of explosive decompression require continued research and development.

Not only the superlative performance of aircraft, but also the reduction of the Army Air Forces to a relatively small group of well chosen men, require adequate and intensive research in selection of personnel.

The field of scientific medicine is in a state of continued and rapid advancement. The medical requirements of Army Air Forces personnel from the standpoint of maintaining flyers in top condition, and from the standpoint of protecting and treating personnel wounded by the weapons employed in war, must continue to be investigated. A detailed consideration of these problems will follow in the remaining sections of this report.

PHYSIOLOGICAL PROBLEMS RELATING TO FLIGHT
IN MODERN AND ULTRAMODERN AIRCRAFT

HUMAN STRESSES RESULTING FROM HIGH SPEED FLIGHT

Speed is the outstanding characteristic of modern aircraft and no doubt will be so of aircraft of the future. Speed coupled with the ability to fly at extreme altitudes where the air is rarified and resistance to motion is very low results in traversing of distances in an extraordinarily short time. The accomplishments of flying very fast and very high are extremely significant; they afford a tremendous impetus to the development and perfection of aircraft and they create certain stresses and hazards which are extremely critical to human pilots or occupants of such aircraft. Fortunately, the United States Army Air Forces has personnel with a comparatively high level of technical training or the capability for such training.

During normal flight at great speeds appreciable distances are traversed in a fraction of a second; marked changes in altitude occur rapidly; deviations from a straight course produce g effects; the balance mechanism of the human occupant is affected, and the action of the slipstream in passing over the external surface of the aircraft and through the engines may set up sonic and supersonic noise and vibrations of considerable intensities. The adiabatic temperature increase at low altitude on a hot summer day can make the cockpit unbearably hot. At speeds greatly in excess of the speed of sound the outer skin or covering of the aircraft would become increasingly hot. To eliminate the hazards of flight at such high speed, these factors and their influence on the human being must be assessed.

At a nominal speed of 600 mph (ground level) the distance traversed in one second is 880 ft and in 0.2 sec is 176 ft. Every action of the pilot is separated from the action-eliciting stimulus by an inherent time lag, called "reaction time." The magnitude of this lag for simple reactions is approximately 0.2 sec or, in distance traversed, 176 ft. This simple observation carries the astouding implication that a human being is incapable of reaction within the time interval, and within the distance mentioned, when traveling at 600 mph. If the action-eliciting stimulus is of a nature to warrant change of altitude or attitude of the plane, aiming and firing a gun, and so forth, the total time lag increases by an amount equivalent to the mechanical lag, and makes the total "dead" time or reactionless time even greater. For discriminative reactions the reaction time may be 0.4 sec or more. The times presuppose that the controls are immediately at hand and that there is a state of readiness to respond appropriately. The effect of anoxia and acceleration on reaction time is relatively unknown.

To keep this reactionless period at a minimum and to prevent the occurrence of situations which require action in less than 0.2 sec, it is necessary that vision be undisturbed and that pilots selected be able to meet maximal visual standards in such attributes as acuity, depth perception, color vision, muscle balance and night vision. The physiologic difference between night and day vision is illustrated in Fig. 1. Fundamental visual research on the perception of stimuli of extremely short duration and the immediately succeeding ones and the relation to the visual standards are indicated, as well as test methods for pilot selection. Proper training after such selection is necessary on a periodic basis. In addition to vision, hearing must not be impaired and fundamental research on the effect of sonic and supersonic noise and vibration on the auditory threshold and the flyer as a whole certainly should be instigated. Development of automatic flying devices diminshes the need for the selection and maintenance of individuals in perfect physical condition, thereby shifting the emphasis to mental capacity. The use of automatic annunciators for announcing altitude, air speed and other flight information directly to the crew deserves intensive investigation. Tone signals attached to the gyrodirection indicator are a comparatively easy problem.

Deviations from a straight flying course at high speeds, or acrobatic flying, will produce accelerations of magnitudes which have a significant effect on human beings equally important as the mechanical stresses on the plane itself. A suit designed for protection against acceleration in the direction foot-head, or positive g, has been developed and its limitations already have been stated. Much of the research pertaining to development of this anti-g suit has been of a practical nature. A great deal of fundamental research remains to be carried out on humans and animals. Some of the problems are indicated below.

Fundamental physiologic studies are needed to elucidate further the mechanisms which underlie the response of human beings and animals to exposure to acceleration on centrifuges and in flight.

For use in bio-assays of g tolerance, investigators need an objective end-point which can apply to animals as well as to man. Direct recordings of arterial blood pressure, photoelectric recordings of pulse from different parts of the head, and the retinogram, should be explored. One of the chief purposes of this study will be to establish a method to be used in appraising the effects of acceleration on animals.

Once this method has been established it will be possible, by removing various reflex control mechanisms and ascertaining the effects of such removal on g tolerance, to study on animals the source of reflexes responsible for vascular compensation in the presence of increased positive g. Such studies should include denervation of the carotid sinus, interruption of the vagal and sympathetic nervous supply to the heart, adrenalectomy and various combinations of these procedures. Some studies of this nature have been carried out in Germany and Japan.

Complete studies should be made on the effects of positive g of a duration of 1, 2, 3, 4 and 5 sec. Such studies will provide information as to the minimal time required for blackout to be produced and as to the blackout level of man at each of these intervals of time. Making very quick turns may be one method of eluding guided missiles. Studies of this sort require use of a centrifuge in which it is possible to attain appreciable levels of positive g in one second or less. (The new superstructure now on order for the Air Materiel Command centrifuge provides the means for achieving acceleration in this time.) Illustrations of the present centrifuge at Wright Field are shown in Figs. 2, 3 and 4. A typical record is reproduced in Fig. 5. It was a surprise

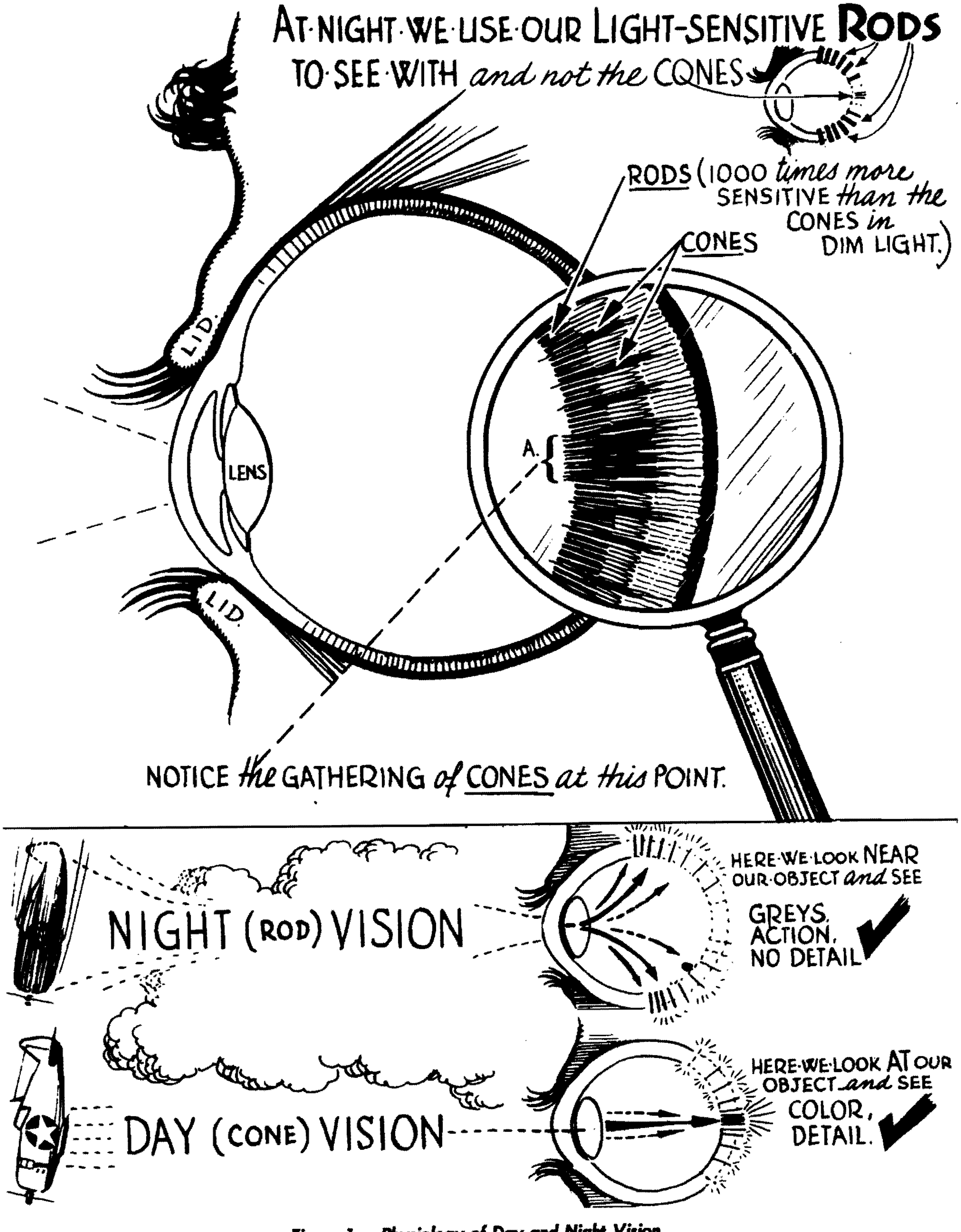
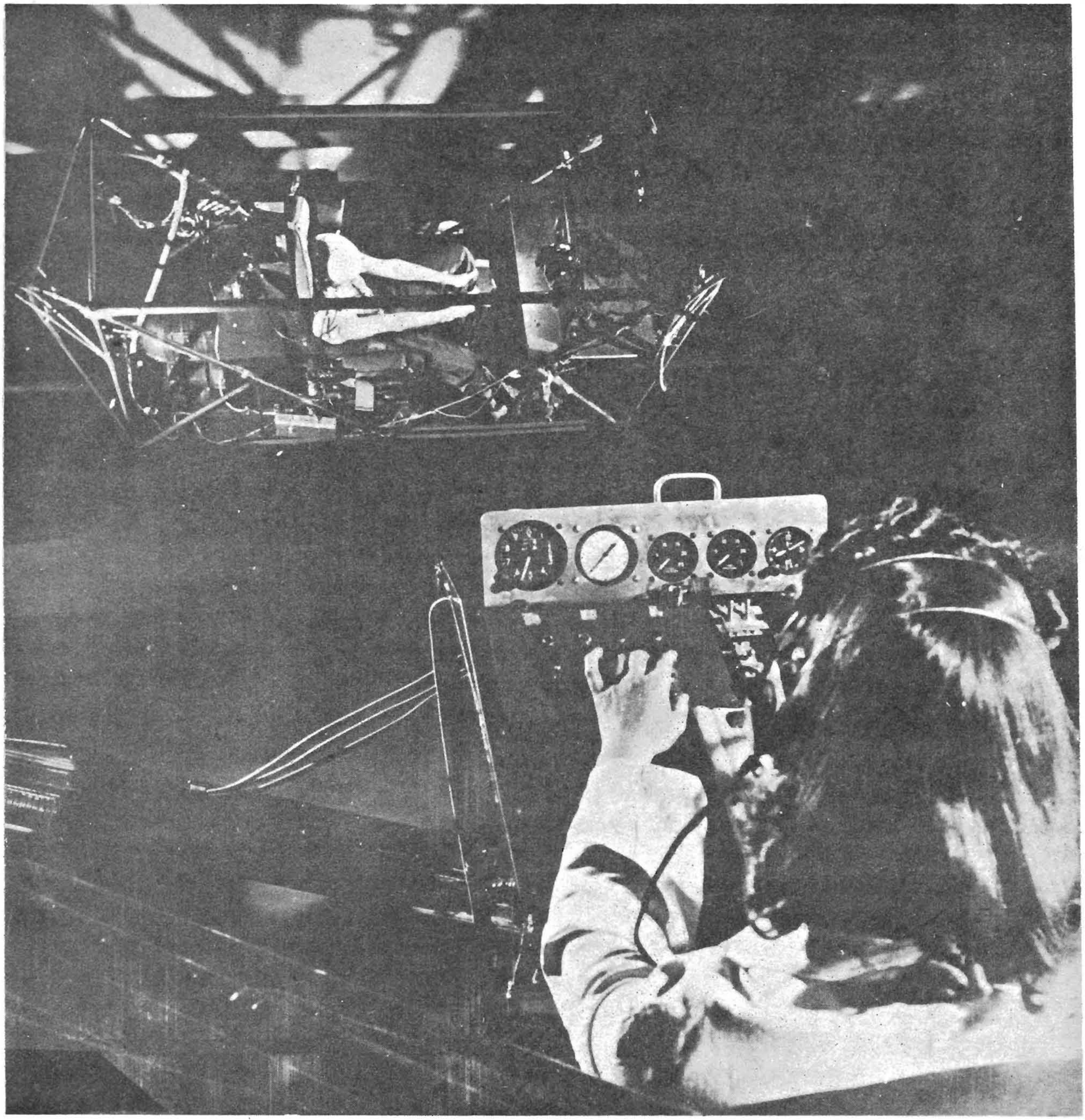


Figure 1 — Physiology of Day and Night Vision



Figures 2 & 3 — Wright Field Centrifuge — Rotating for 5.5 G.

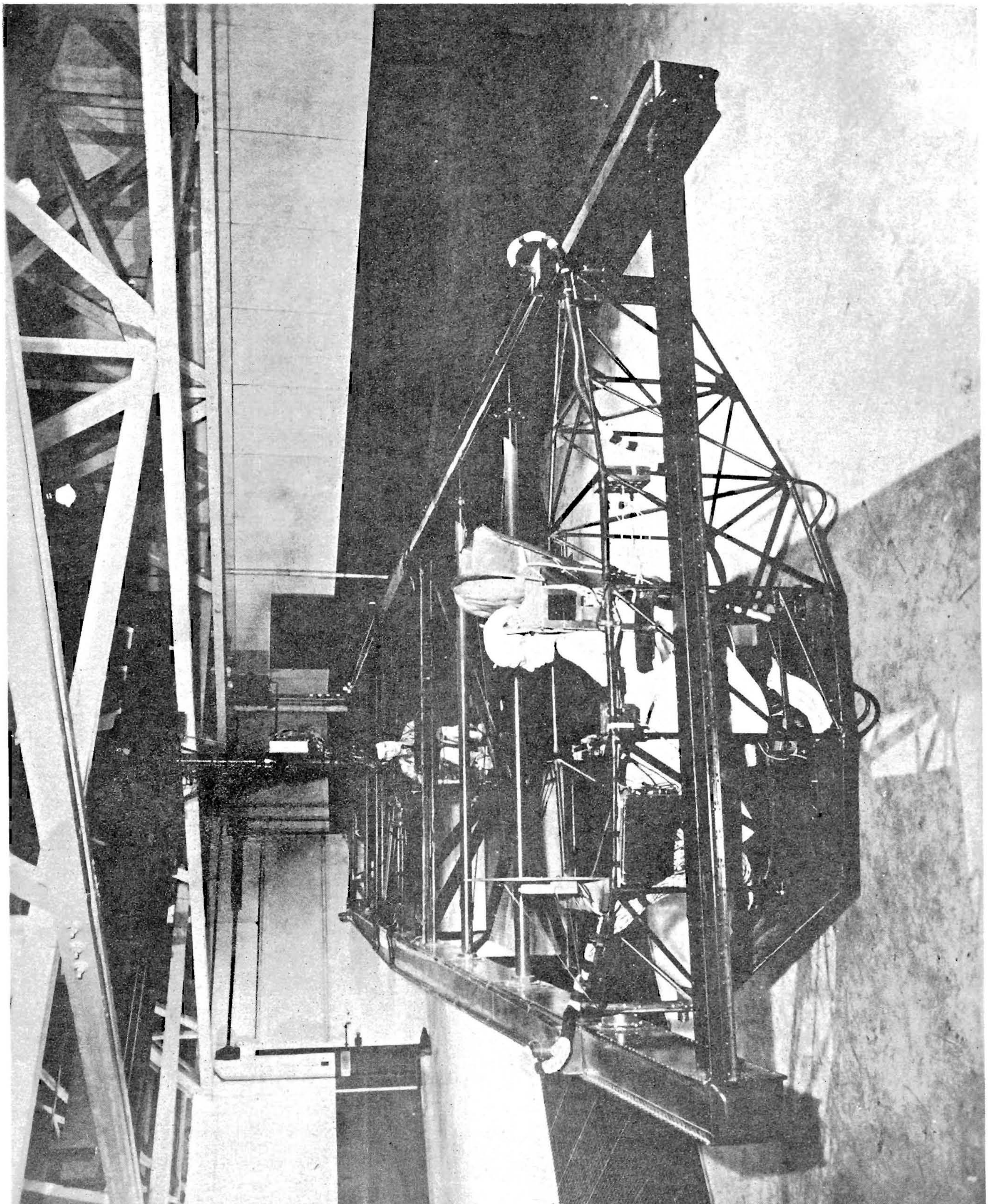


Figure 4 — Wright Field Centrifuge

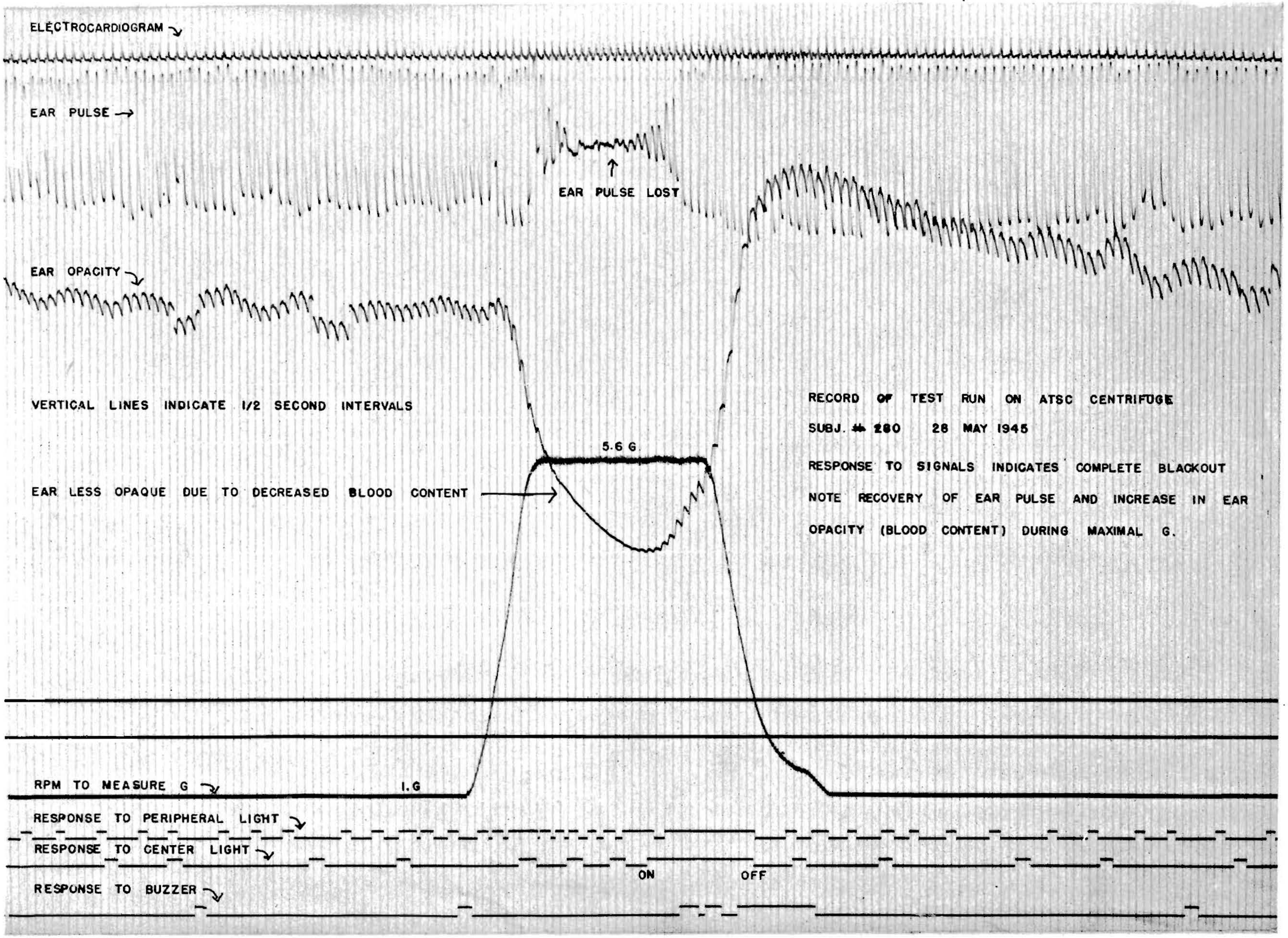
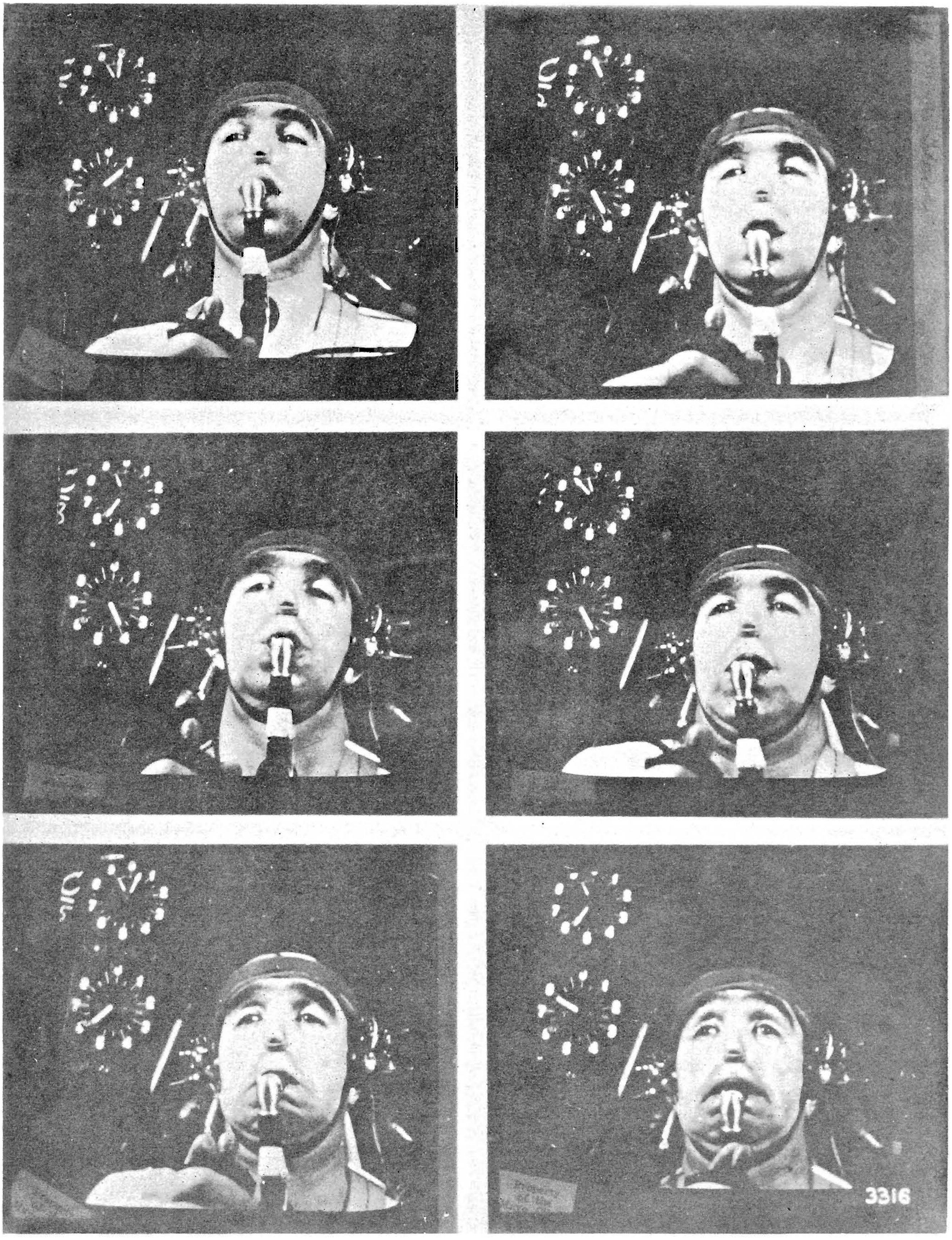


Figure 5 — Effects of Centrifugal Force on Human Subject



Figures 6 & 7 — Facial Changes Occuring During Increasing "G" (1 to 8)

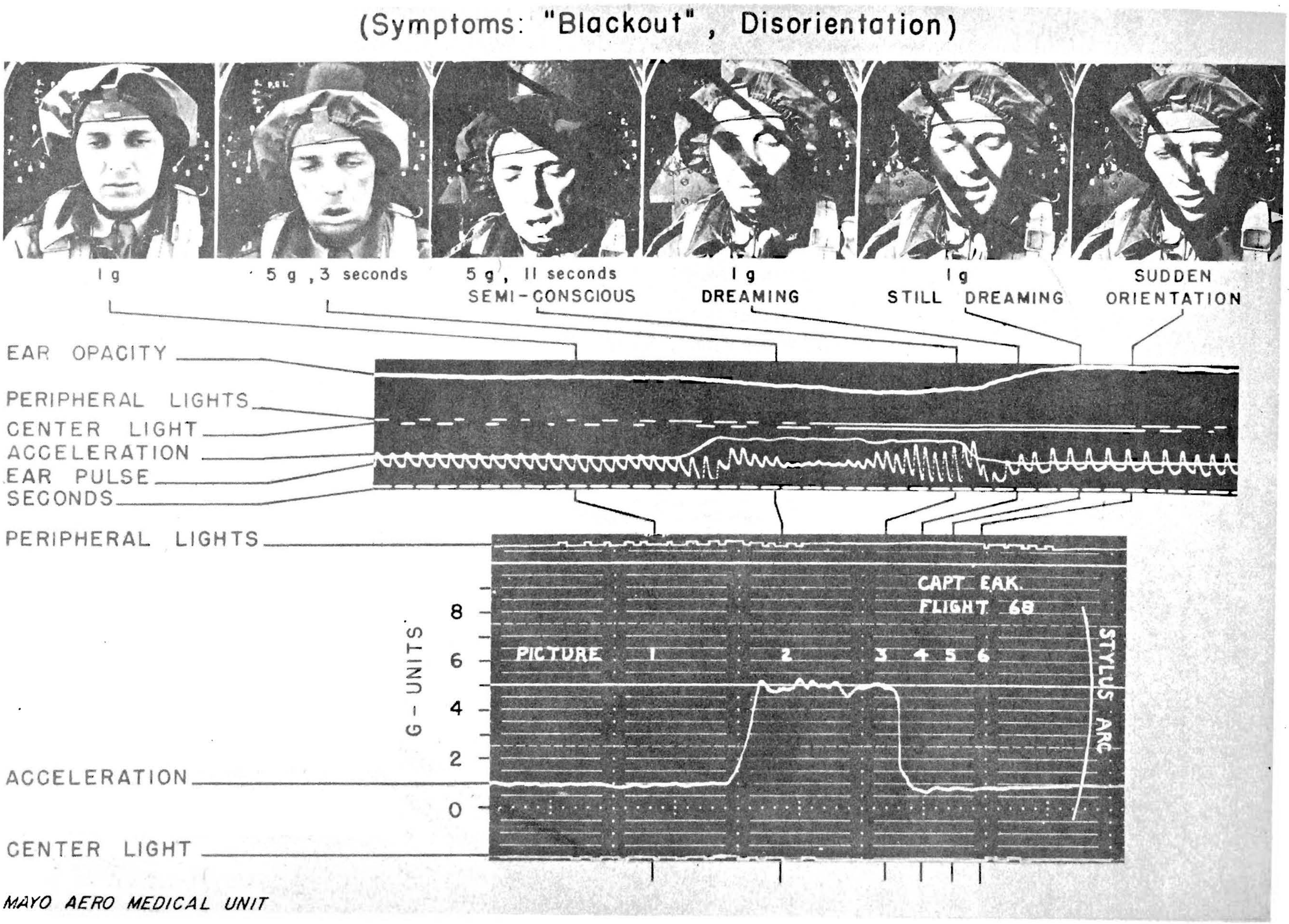


Figure 8 — Unprotected Passenger in A-24 Airplane. (5.0 G)

to find that the Japanese had two human and seven animal centrifuges. The human centrifuges were not as useful as those in the United States Army Air Forces since one had a radius of only 9 ft and the other one took too long to attain g. The subject could be kept in only one position during the run, and their instrumentation was not as good as that of the Army Air Forces. The human centrifuges used by the German Air Force had too small a radius which caused them to obtain results that were erroneous from a combat standpoint, and which in turn resulted in unnecessary losses of German Air Force personnel.

Further studies should be carried out on the phenomenon of physiologic compensation in man during exposure to positive g. The minimal force required to evoke such compensation, together with the time such force must act, should be determined. Photographs of subjects under various g forces are shown in Figs. 6, 7 and 8.

Further studies are greatly needed in the field of negative g, including a study of the effect of exposure to negative g on a subsequent rapid exposure to positive g. These must be done with great care to avoid accidents. (The new superstructure to be provided for the Air Materiel Command centrifuge will permit such studies to be carried out.) The effect of various head movements during g should be determined. All flyers should have a determination of their g tolerance made on the human centrifuge.

The effect on g tolerance of such factors as anoxia, cold, heat, fever and the post-febrile state, food intake, fluid intake, oxygen lack, carbon dioxide excess and graded exposure to carbon monoxide should be determined. Personnel in the Japanese Army Air Force found that administration of a barium meal followed by an exposure of 10 sec at 4.5 g resulted in a 30-min delay in the emptying time of the stomach. Further studies of this type on animals and humans are indicated.

The effectiveness of present anti-g equipment in meeting the changes in tactics associated with the development of faster fighter aircraft must be constantly checked. Figs. 9, 10 and 11 indicate the changing relationship between g and the radius of turn as velocities increase, to values higher than those now reached.

Further work is needed on the g suit to approach the ideal of a flying suit incorporating g protective and, if possible, crash-protective features but so simple and comfortable that it can be worn routinely whether g protection is required or not. Further studies are needed to increase the protection offered by present-day g suits in anticipation of future needs.

The maneuvers required by the Eighth Air Force fighter operations produced grayout and blackout in a high proportion of pilots which made it apparent that their combat efficiency was decreased at critical moments. On the basis of the results given below it was concluded that the g suit was an important factor in increasing the combat efficiency of the P-51 pilot-aircraft combination. German scientists admitted that they should have developed a g suit. The use of an abdominal belt by pilots in the Japanese Air Force was only of small help, but that in combination with the M-1 maneuver was of value.

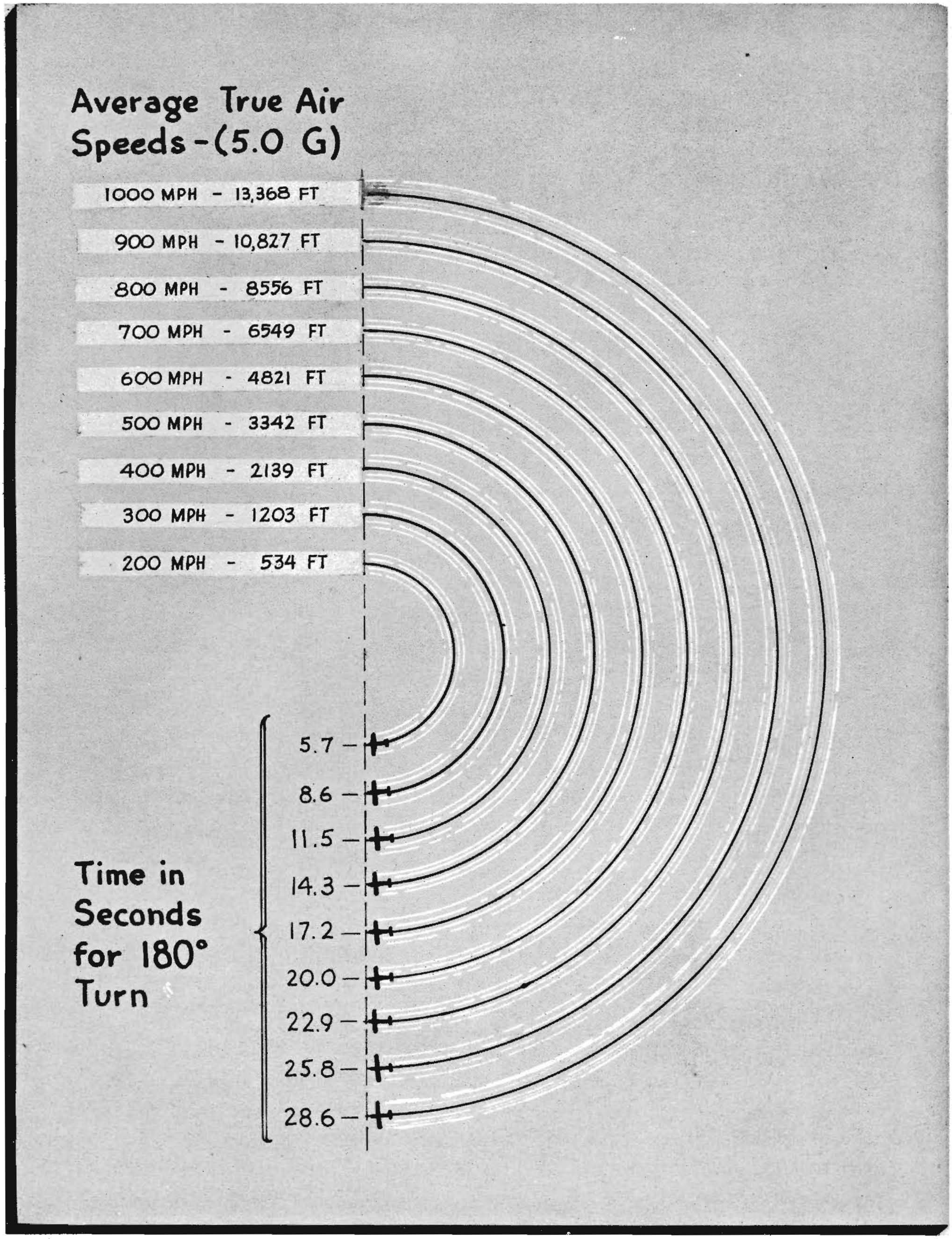
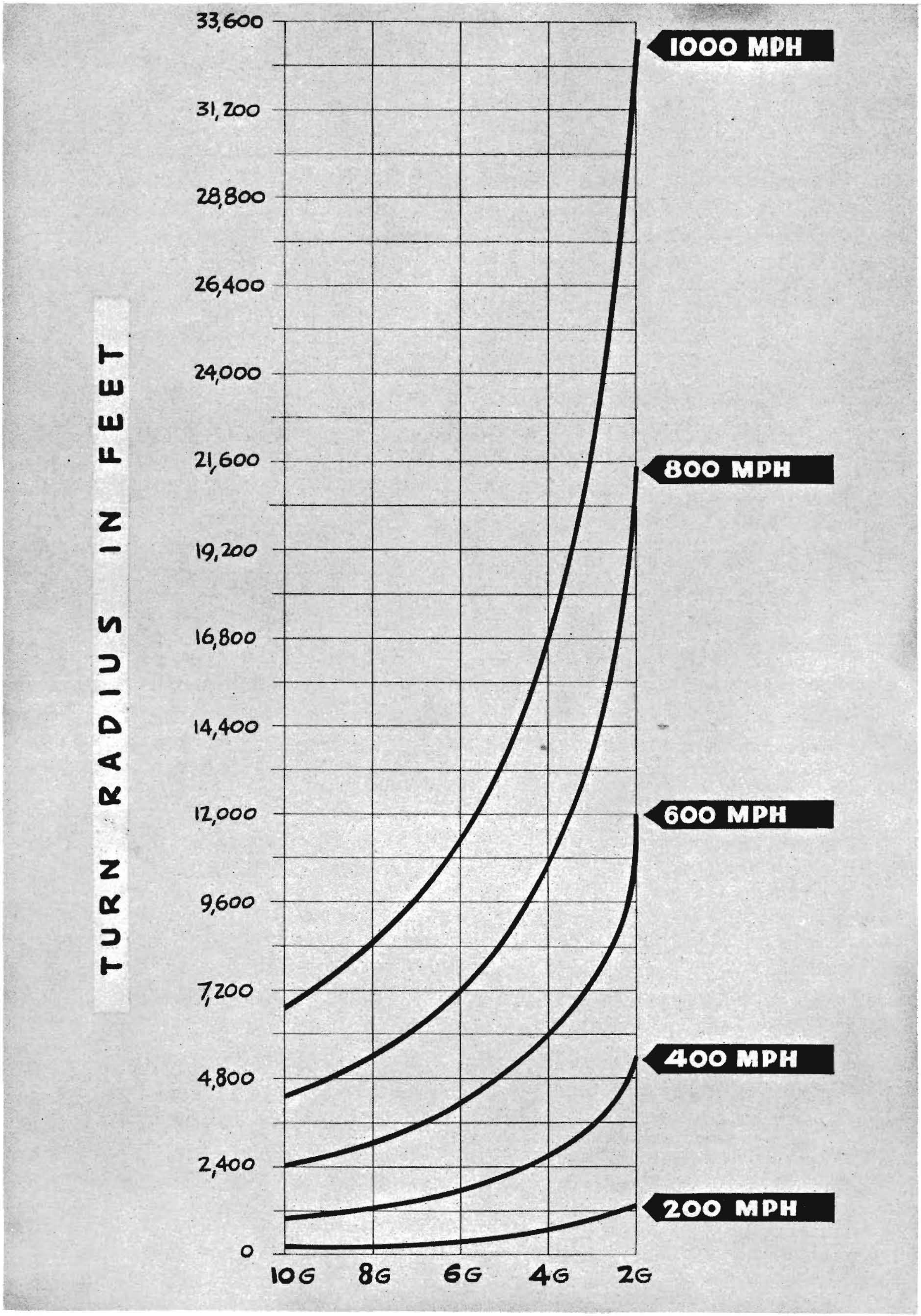


Figure 9 — Radius of Aircraft Turn Required to Blackout Average Pilot at Various True Air Speeds. (5.0 G)



Figures 10 & 11 — "G" Force Resulting from Various Radius of Turn with Constant Speed

Relationship Between Use of G Suit and Enemy Aircraft Shot Down

	No. of A/C shot down	*No. of sorties*	*No. of oper. hr.*	*No. A/C shot down per 1000 sorties*	*No. A/C shot down per 10,000 oper. hr.*
Wearing g suit	87	3,048	13,059	29	67
Not wearing g suit	58	3,911	17,362	16	33

A study designed to give an estimate of the restrictions placed on man's locomotive ability by the application of radial g (centrifugal force) was made on the human centrifuge. Five subjects were studied. The results were as follows:

1. Movement in the same direction as the radial force. Movement in this direction was easy but hazardous. Falling one foot at 2 g was sufficient to knock the wind out of subjects. It was concluded that falls of greater distances at slightly higher accelerations would often cause injury.

2. Movement at right angles to the radial g.

   a. On the average the time required to crawl across the end of the centrifuge, a distance of 7-1/2 ft, was increased 2-1/4 times by 1 radial g, 5 times by 2 radial g, and 10 times by 3 radial g. Three of five subjects tested could not accomplish this task at 4 g.

   b. The time required to round a barrier which projected 22 in. from the back of the centrifuge was increased 2-1/4 times by 1 radial g, 6 times by 2 radial g, and 18 times by 3 radial g. The subjects stated they could not accomplish the task at 4 g.

The results indicate the tremendous increase in time required to perform simple movements of the body under radial g. At 4 g even these simple movements became impossible for most subjects.

3. Movement against the radial g. Against a force of 2 to 3 g it became impossible for the subjects to crawl, walk, climb a rope or a ladder or rise from a bomber seat. The results indicate that escape maneuvers of a flyer directed against the accelerative force may often be ineffective if this force is in the neighborhood of 3 g.

4. Donning a parachute when exposed to radial g. The average time required for three subjects to don a standard back parachute was 17 sec at 1 g. This was increased to 21 sec at 1 g radial, 41 sec at 2 g raidal and 1 min 15 sec at 3 g radial. One of the three subjects was unable to complete the task at 3 g. It was uniformly agreed that at an acceleration slightly above 3 g the parachute could not have been donned by any of the subjects.

The acceleration developed in rocket-propelled take-offs of piloted aircraft will be limited by the pilot or personnel being carried. Such personnel might conceivably be in either the seated or the prone position. Vertical take-off of certain types of interceptor aircraft is a distinct possibility.

With the pilot in the seated position, linear acceleration of this type would produce transverse g relative to the pilot. It will be important to learn what maximal g in this direction can be tolerated, and still allow the pilot to perform accurate movements with his hands and feet, and also to determine the maximal g in this direction which can be tolerated by a pilot who has no responsibilities of this sort during the acceleration of the take-off.

If the pilot is in the prone position, head forward, linear acceleration at take-off would represent positive g relative to the pilot. On landing negative g would be experienced. The tolerance of man to positive g when he is fully stretched out is known to be very low. It will be important to know what this limiting factor is, and if necessary, to develop measures to elevate it. Should the supine position be used, the force associated with linear acceleration will be negative g as far as the pilot is concerned, if his head is facing aft. Again the limiting g for this position should be determined.

The limiting effect of centripetal acceleration on man's ability to move has been demonstrated on the human centrifuge as a means of appraising some of the difficulties which may be encountered when attempting escape from spinning aircraft. The results were sufficiently striking and definite to justify reevaluation of emergency escape from spinning aircraft.

The events during flight which cause g also cause motion sickness. There is some evidence from the Russian Air Force that elementary tumbling exercises will condition personnel against motion sickness resulting from disturbance of the semicircular canals. Medical personnel in the Japanese Air Force are strong advocates of a system of exercises designed to stimulate the semicircular canals, and claim this has resulted not only in a decrease in motion sickness but also that it is made easier for the cadets in training to orient themselves during aerobatics. Investigations in the value of this conditioning process should be carried out, as well as fundamental research on the physiologic and psychologic causes of motion sickness, to determine to what extent motion sickness is caused by visual disturbances, by conflicting sensations, by neurotic traits, by movements of the viscera, by position in the aircraft and other contributory factors. Solution of the problem will be possible, only when further research on fundamental physiology is completed.

Data from the German Air Force indicate that sonic and supersonic vibrations of considerable intensities are generated during flight of Me-262 jet-propelled aircraft and that the intensity of these vibrations varies directly with speed of flight. If generation of these vibrations cannot be prevented, then fundamental research must be carried out concerning their effect on the auditory threshold throughout the auditory spectrum, and the possible injurious effects on living tissues. The dampening effect of the body on vibrations is unknown. The initiation of a research program in this field certainly is indicated, since such a program does not now exist in the Army Air Forces. Data on the effect of vibration obtained from personnel in the Japanese Navy Air Force will prove helpful in establishing this program. The Japanese demonstrated that vibration decreased the accuracy of sighting because of vibration of the eyeball.

Emergency escape produces additional stresses which act on human occupants of high-speed aircraft. Sufficient data exist to prove that unaided escape from such aircraft is extremely hazardous and that ejection seats or other powered expelling devices are required for successful escape.

The German Air Force was the first to use vertical ejection of the pilot as a successful method of escape from these high-speed machines. Their studies of accelerative forces encountered in ejection which are tolerable to human beings have been very thorough and data have been presented showing that successful escape can be made at speeds up to 560 mph. Since aircraft capable of speeds of 600 mph, or greater will be flying in the very near future, and since this speed will be exceeded in the more distant future, it is essential that these basic studies of the Germans be extended to higher velocities. The following steps will be necessary:

1. Determination of safe maximal forces for man in upward as well as downward ejection from aircraft. This will involve exposure of man to a graded ejection force on an indoctrination vertical accelerator, and is primarily a question of structural limitations of the body such as the resistance of the vertebrae to fracture, rather than the physiologic effects such as blackout.

2. Determination of criteria as to the speed required for clearance of aircraft empennage at various speeds of horizontal flight and the g forces occurring on different parts of the body during the procedure. The new Bureau of Standards accelerometer has made this possible.

3. Measurements of the effect of wind on the human body up to a velocity of 700 mph, and more.

4. Design of equipment to protect the human face from wind of high velocity, including the use of ejectible cockpits at speeds in excess of approximately 500 mph.

5. Wind-tunnel experiments to determine the performance of present personnel equipment for use in the presence of wind of high velocity.

6. Wind-tunnel experiments to determine drag coefficient and lift of the human body in various postures at various speeds up to and beyond supersonic values.

7. Development of a train-type trigger ejection apparatus which will, in proper sequence, jettison the canopy, eject the pilot, drop the seat from him and open the parachute at proper intervals of time.

During an emergency escape from high-speed aircraft, the occupant is projected into a high velocity slip stream and, if the altitude of escape is above 20,000 ft, into one that is very cold. This slip stream acts on all parts of the body with diminishing force until the horizontal velocity becomes negligible. The action of a cold slip stream, and of slip-stream velocities above 560 mph, needs yet to be determined and suitable protective equipment developed.

To complete safely the emergency escape, it is necessary to have a parachute of which the opening shock characteristic is below the threshold of human injury and the landing speed of which is sufficiently slow to prevent injury on landing. Very little information on parachute landing exists, except a large body of data to indicate that the incidence of injury on landing is very high. A systematic program of investigation of factors related to parachute-landing injury such as will be outlined next certainly is indicated.

Research in parachuting is directed to the end of reducing the incidence of injury incurred during the use of parachutes. The elimination of injuries resulting when the jumper strikes part of the aircraft in the course of his escape can be minimized by perfection of the ejection seat. A great deal of information was collected during World War II on the magnitude of parachute opening shock and application of these fundamental data provides a program which, when followed, will minimize injury from this source. The greatest percentage of injuries, however, occur during parachute landing. To date there has been no real study of the decelerative forces which produce injuries of this sort. In mountainous terrain the crew after bailing out may land at an altitude of 10,000 ft or more.

Data on the basic tolerance of man for shock forces transmitted through the body from the feet should be obtained by:

1. Dropping subjects with controlled velocity in an enclosed tower to determine the percentage of injuries at various velocities and thus to establish the minimal diameter of parachute canopy to eliminate landing injury.

2. Determining the distribution of g forces through the human body by measuring the g force at the ankle, knee, hip and head during the same landing.

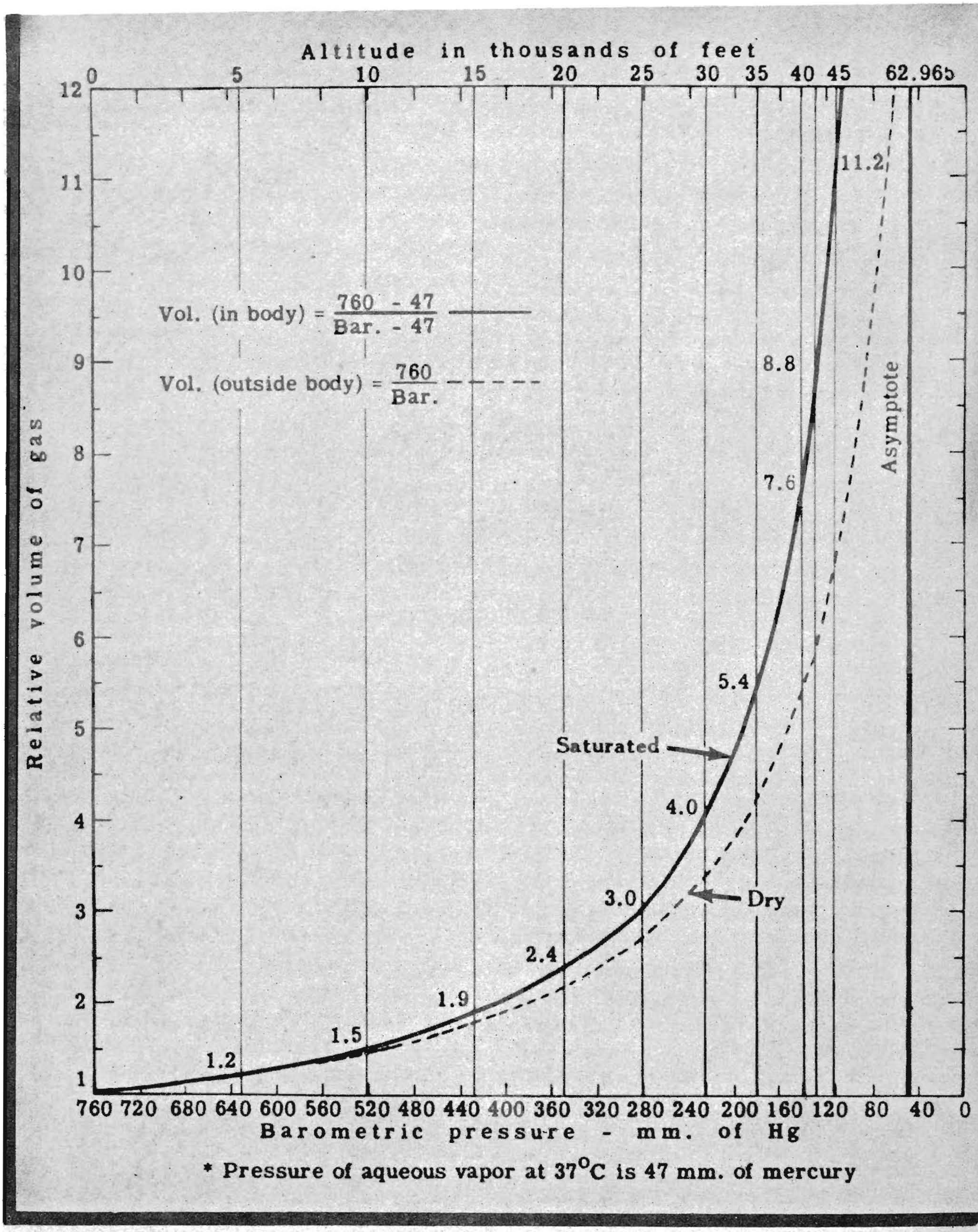
3. Determining the effectiveness of various landing media in producing injuries obtained during landing. This will be done by providing test floorings of various resiliencies.

No satisfactory data on the subject numbered 3, above, have as yet been produced.

HUMAN STRESSES PRODUCED BY FLIGHT AT HIGH ALTITUDE

High-speed, high-altitude aircraft of the present, as well as of the immediate and remote future, have and will have pressurized cabins. The limitations of present equipment already pointed out limit flight to altitudes of 50,000 ft because of possible emergency loss of cabin pressure. In most cases physiologic data exist which would be adequate for the design of equipment within these limitations and the stresses produced during normal flight have been adequately described. Details not yet adequately described must be recorded in final form. The importance of conducting physiologic experiments cannot be overemphasized. Critical human stresses are produced when cabin pressure fails or in the event of emergency escape from aircraft flying at altitudes in excess of 50,000 ft. On loss of cabin pressure the body is placed suddenly in an environment where pressure is reduced. This sudden reduction of environmental pressure causes expansion of gases in the lungs and abdominal organs and causes liberation of gases dissolved in body fluids (Figs. 12 and 13). The intensity of these reactions is a direct function of the magnitude of the reduction of pressure and the interval of time in which this reduction takes place. At a pressure reduced to that equivalent to the pressure at altitudes in excess of 65,000 ft the dissolved gases in body fluids will be liberated in sufficient amounts to cause complete occlusion of the pulmonary cavity and tremendous enlargement of the right side of the heart causing death.

These reactions which result from explosive decompression must continue to be thoroughly investigated so that the injuries produced by expansion and liberation of gas in blood vessels and other tissues may be known. The tolerable limits in time and magnitude of reduction of pressure must be accurately determined and proper protective equipment designed.



* SATURATED AT 37°C OR 98.6°F

Figure 12 — Comparative Volume of Gases Inside the Body at Various Altitudes.

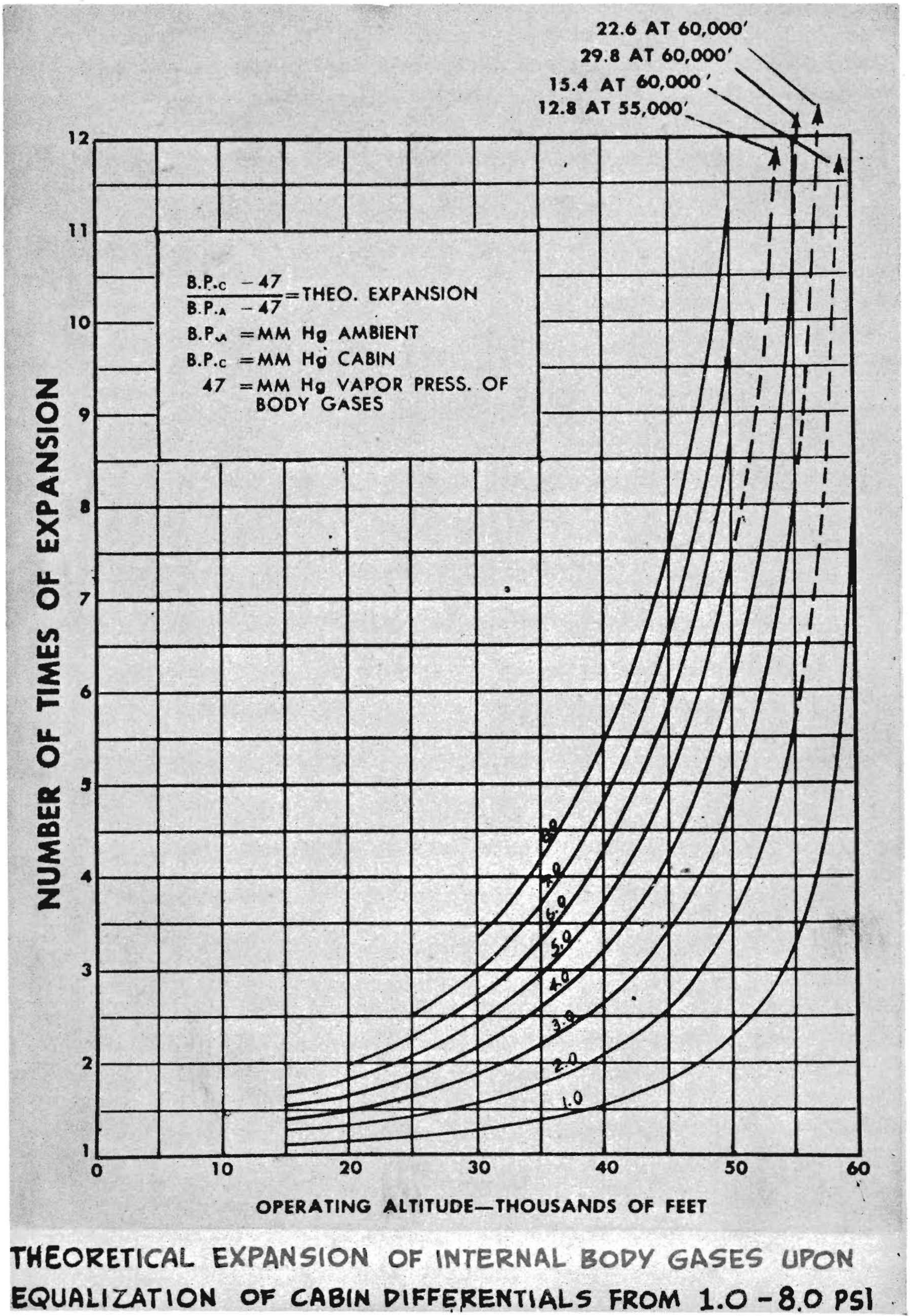


Figure 13 — Relative Expansion of Internal Gases During Explosive Decompression

A second important stress produced by cabin depressurization is the anoxia to which personnel are subject, even if momentarily. The effect of severe anoxia over short periods of time must be thoroughly investigated to determined (1) the time of useful consciousness when breathing air, 100% oxygen at ambient pressure and pressurized oxygen; to determine (2) the time required for injury under these various conditions; and to determine (3) the time required for death under these conditions. In conjunction with such a program there should take place experimentation on the rate of free fall of the clothed human body at extreme altitudes and on the rate of freezing of human tissues exposed to substratospheric temperatures. These values must be determined in order to establish the requirements for equipment and for reliable escape procedures. Acclimatization is considered to be of importance by scientists in Germany as it was shown that it resulted not only in an increased altitude tolerance of about 2000 ft but also in an increase in the period of effective consciousness. At high altitudes this increased time reserve may mean the difference between taking the necessary steps to cope with the emergency, or the pilot's becoming unconscious before being able to take these steps. Early establishment of a permanent high-altitude research laboratory in the United States on Pikes Peak, Mt. Ranier or some similar location would provide an ideal location for carrying out studies on acclimatization to altitude, cold and other physiologic problems occuring at such an altitude. The Jungfraujoch scientific station built by the Swiss in 1931 at an altitude of 3457 m, and directed by the Jungfraujoch commission has been used by many scientists interested in carrying out research at high altitudes in the mountains.

It should be emphasized once again that research on basic aspects of flying safety, including instrument flying (an absolute necessity for a global air force), must be continued in order to reduce casualties and injuries. A specific example is the investigation outlined below, of the cause and prevention of crash landing injuries, which injuries result from linear deceleration.

HUMAN STRESSES PRODUCED BY CRASHING AND DITCHING AIRCRAFT

Experimental work is virtually nonexistent on important factors involved in protecting man from the sudden deceleration which occurs in crash landings and in ditching. All pilots should have some training with seaplanes so that they will know how to ditch an aircraft better. Present calculations of the forces concerned in aircraft accidents are based on measurements of the path of deceleration and assumed velocities, and are essentially useless. Solution of the problem demands development of methods to apply deceleration from velocities up to 200 mph so that the time factor remains in the range of that of decelerations which occur in aircraft crashes. Such methods must also include accurate means of measuring the accelerative forces. A rocket-propelled cart to be used for this purpose is planned.

The minimum requirements are an acceleration of the loaded cart not in excess of 10 g, but in any case, a minimum speed of 120 mph, the acceleration period to be followed by a period of approximately 0.1 sec, involving about 20 ft of track during which there is no acceleration, and then leading up to a controlled deceleration over a distance of about 10 ft wherein the deceleration may be varied, depending on the speed as well as the decelerating mechanism, up to 100 g.

When carrying out experiments, special equipment would include: high-frequency accelerometer attached to the seat, harness, dummy or man and other apparatus; high-speed Fastex cameras synchronized with oscillograph recordings so that the force as well as the time could be determined when failure occurred; and a 12-element oscillograph with approximately the following readings; strain gauge accelerometer on cart, accelerometer on seat, accelerometer on dummy, spare accelerometer; relative motion of the dummy with respect to cart measured from the front; relative motion of the dummy with respect to cart measured from the back; interval velocity of cart during entire run; 1000-c time marker, synchronization of Fastex camera using an electric spark; photoelectric synchronization with Edgerton flash technic, measurement of pressure in the hydraulic decelerators and in air pressure tank; and seismographic or sound record of crash. An inertia type of accelerator and a modification of the navy type of catapult are planned for use at Wright Field. With this device equipped with the proper instruments, means will be available to study the forces in question. It should be possible to compare dynamic and static testing of material, to determine the magnitude of decelerative forces which can be withstood by present and experimental equipment, such as seats, parachute harness, inertia lock and safety harnesses, and the magnitude of decelerations which can be withstood by animals and finally by man when he is properly protected. From these determinations, it should be possible to learn the proper stressing to be applied to seats and protective harnesses in aircraft. Only when basic information of this type has been obtained will it be possible to design aircraft with maximal and proper factors. Determination of the magnitude of forces in aircraft accidents requires the crashing of salvage aircraft. The pattern of disintegration should be studied by high-speed motion pictures taken at a distance with telephoto lenses. The accelerative forces incurred at various stations within the aircraft could be obtained by appropriate high-frequency accelerometers. Correlation of the forces with the degree of disintegration of aircraft would provide data for use in appraising conditions at investigations of aircraft accidents.

PERSONAL EQUIPMENT AND OXYGEN EQUIPMENT

As long as the environment in aircraft cabins is not similar to that encountered in everyday experience on the ground, and as long as there is a likelihood of loss of cabin pressure, bailout or crash, there will be continued need for development of personal equipment and oxygen equipment. In transport aircraft there is already less need than formerly for special equipment for crews and passengers. But tactical aircraft are built for an entirely different purpose, and the problems of personal equipment suitable for use under a wide variety of conditions any place in the world, for the crews no doubt, will continue indefinitely. The care of personal equipment can best be handled by personal equipment officers.

AIR-SEA RESCUE

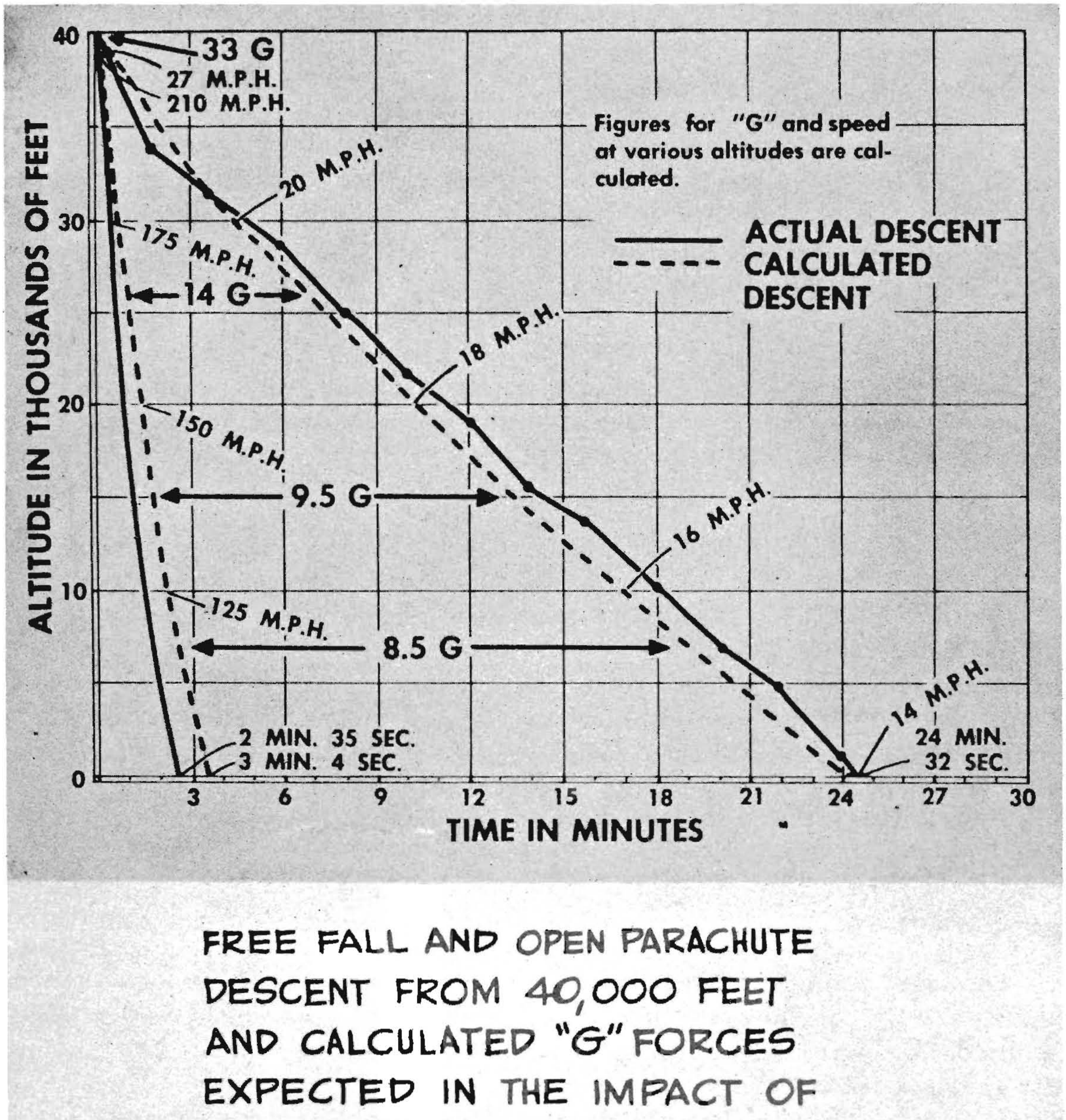
Survival on land and sea requires investigation in the aeromedical aspects of air-sea rescue equipment, ditching and survival procedures.

Air-sea rescue equipment is usually divided into two categories: items necessary for survival, and items necessary for signalling and communication. In the first category, continued development will be required on solar stills, and Permutit kits for making sea water potable, continuous wear exposure suits, life raft rations, first aid kits and glare goggles. In the second category are flares, automatic radio and radar equipment and color and smoke signalling devices. Also included are sun glasses for search crews. The emphasis on each of these categories is determined by the nature of the terrain and the extent of air-sea rescue facilities available. The longer the range of aircraft, the more chance there is of flying over larger areas of the ocean and different types of terrain. Simultaneously, development of compact life raft equipment together with the necessary escape components and effective methods of storage must be continued. Life rafts can be designed to be more seaworthy, easier to board and row and possibly to have an insulated floor. Experience in the past war has shown there is a high correlation between effective air-sea rescue facilities and morale.

In the nature of ditching and survival procedures for aircraft which carry patients, practical testing simulating the actual conditions will be required. Present pencil and paper studies are not adequate. The majority of patients can be removed from litters and many can move under their own power in case of ditching. A larger raft should be devised so that patients can be placed in a reclining position. The kits furnished with these rafts should contain adequate medical supplies.

PARACHUTES

The following design criteria for parachutes should be met: low opening shock, almost instantaneous opening, simple quick release mechanism, descent free of pendulation and automatic opening device. At present, it is considered unsafe to open a standard parachute immediately on bailout above 20,000 ft because of the high opening shock, which is from 20 to 50 g (Fig. 14). Investigation of methods of alleviating



FREE FALL AND OPEN PARACHUTE DESCENT FROM 40,000 FEET AND CALCULATED "G" FORCES EXPECTED IN THE IMPACT OF PARACHUTE OPENING AT VARIOUS ALTITUDES.

Figure 14 — Opening Shocks and Time of Descent

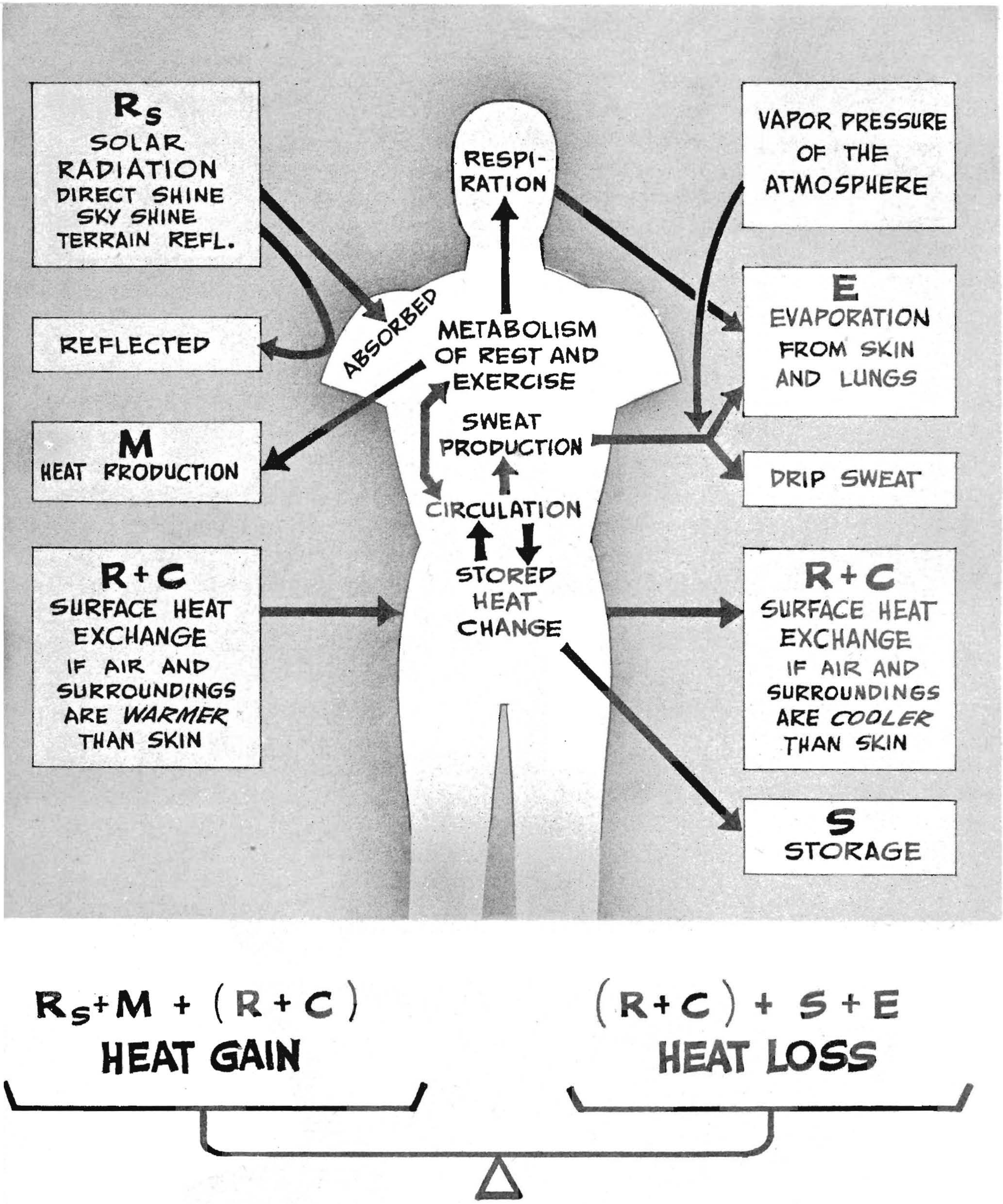
opening shock at high altitude by altering canopy design must be made. This project foresees the testing of canopies with holes, of canopies of unconventional shapes and of restricted rates of deployment. The Germans realized that the opening shock was great at high altitudes but felt that malorientation of the body was the primary cause of injury during high altitude bailout. Their proposed solution was an orienting parachute to turn the body properly before opening of the main chute. They presented, however, no evidence that they realized the opening shock was as high as has been demonstrated by the Army Air Forces. As a rule, the Germans emphasized the danegr of anoxia for high-altitude bailout rather than the danger from opening shock. Of course, both factors should have equal consideration.

In the previous paragraph, it was stated that studies of the design of new types of canopies must be made. The investigation further requires establishment of basic information as to the effect of speed and size of the canopy on parachute opening shock and the factors, such as the parachute harness and the aircraft slip stream, which may affect such shock. The German "ribbon" parachute was designed to answer the high-speed bailout question. Successful bailout from high-speed aircraft flying at altitudes of from 100 to 200 ft remains an extremely difficult problem and emphasizes the need for a parachute that will open almost instantaneously. Simple and light quick release devices are strongly indicated as evidenced by the fact that such devices were in use by the German and Japanese Air Force and by the Air Forces of our allies.

Whenever bailout followed by free fall is made from altitudes of 30,000 ft and higher, anoxia and possible unconsciousness of the jumper may prevent him from opening his chute at lower altitudes. Automatic parachute opening devices may be either altitude or time controlled. The attachment of a static line to the fuselage of the aircraft as practiced by many flyers in the Japanese Air Force does not seem feasible. It should be noted that the development of an automatic opening device should proceed concomitantly with the development of an automatic oxygen bailout bottle and a body harness that will properly distribute the load over the body when the parachute opens, and that will serve both for the parachute and for the present separate should harness and seat belt.

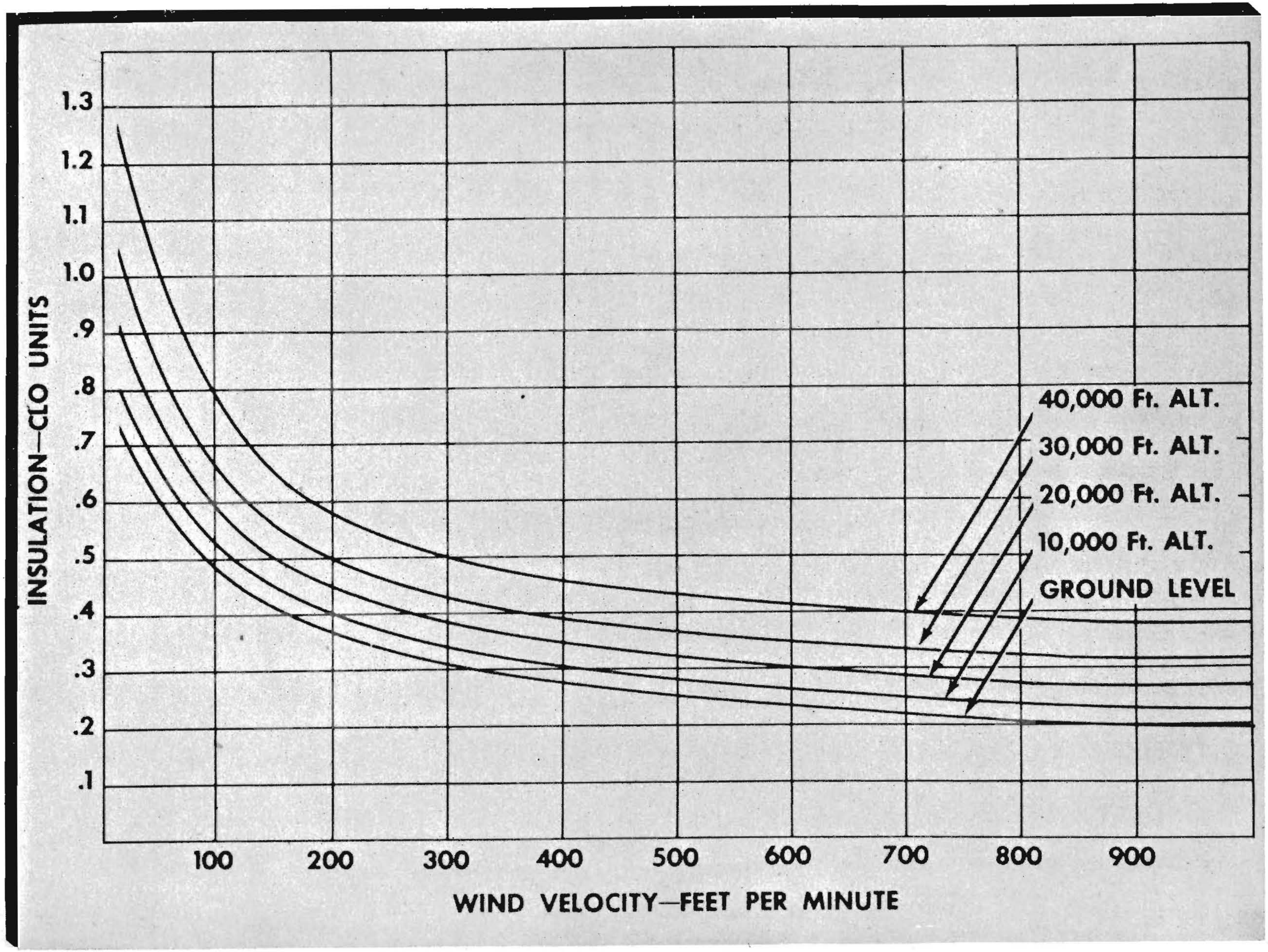
FLYING CLOTHES

Continued research will be necessary to evaluate flying clothing for use under varying climatic conditions in different parts of the world from the physiologic standpoint as new designs and new materials are provided. Studies on the thermal balance of man exposed to heat (Fig. 15) is a new field as well as is the effect of wind in the cold and at altitude (Figs. 16, 17 and 18). Specialized clothing for fire fighting and fire protection also will be studied. Aluminized clothing has been used successfully by the Germans for protection of personnel who fight fires. Similar clothing has been developed by the National Research Council of Canada for use as a protection against cold, by reducing the effect of irradiation. Aluminized clothing should be investigated for its possible protection and safety value for aircrews, and for use by fire-fighting teams in emergency. Crews flying in jet- or rocket-propelled aircraft powered by fuel (such as 80% hydrogen peroxide which on contact is harmful to humans) must have protective clothing in case of enemy damage to the aircraft or mechanical



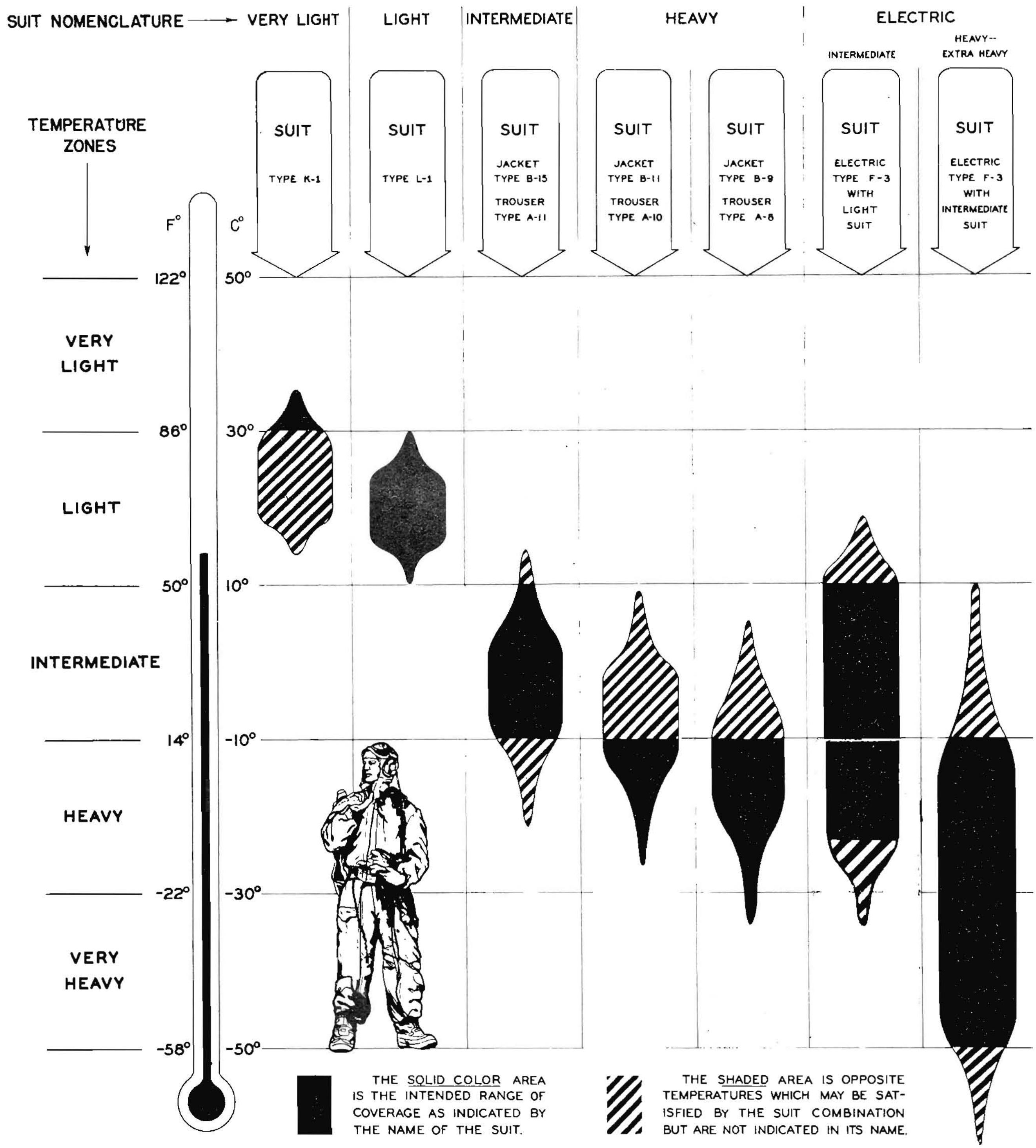
SCHEMATIC VIEW OF HUMAN HEAT BALANCE WHEN EXPOSED TO A HOT AND HUMID ENVIRONMENT.

Figure 15 — Thermal Balance of Man



*INSULATION EXPRESSED IN TERMS OF CLO VALUE

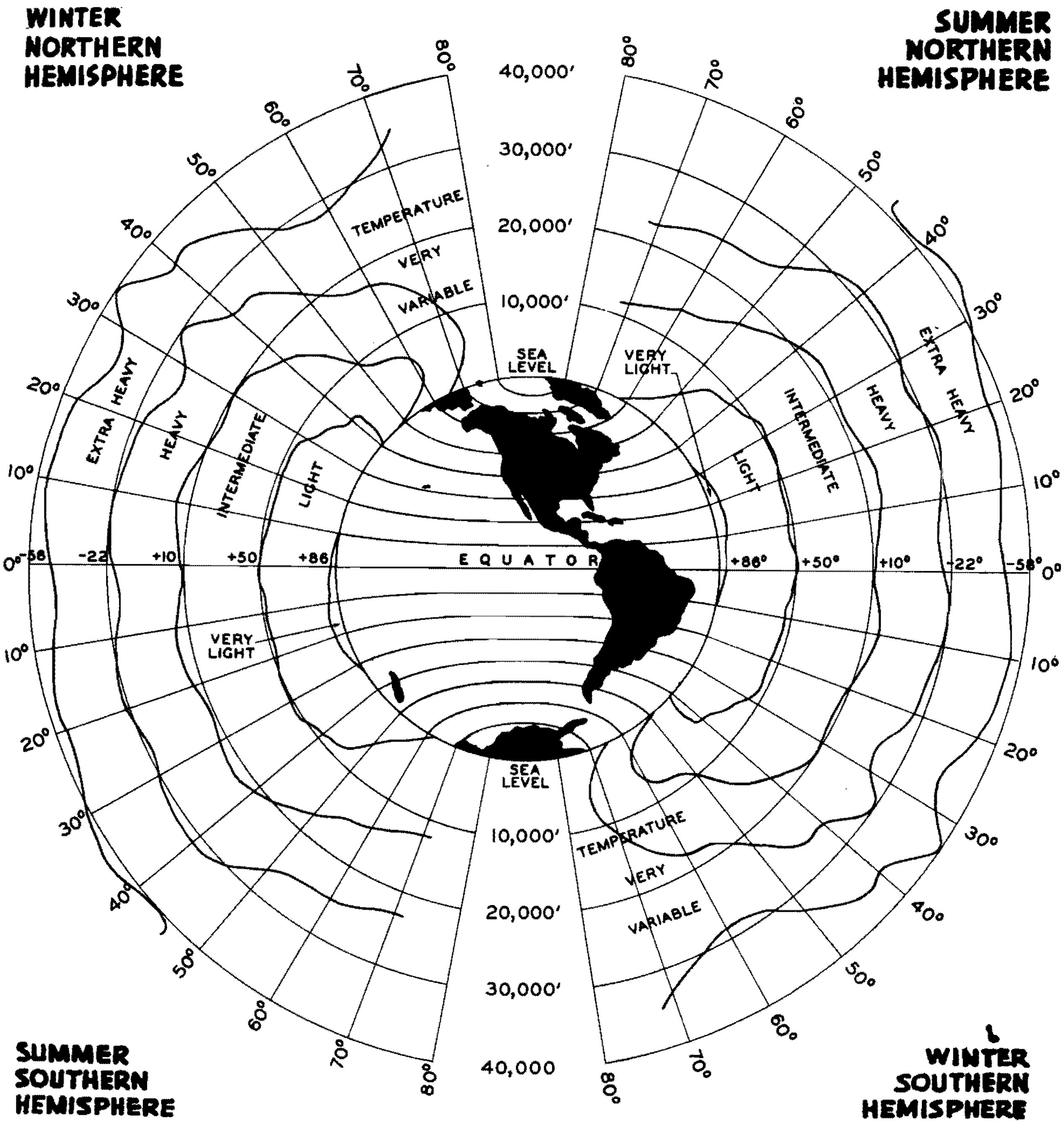
Figure 16 — Relation at Various Altitudes between Wind Velocity and Insulation Provided by Layer of Air



● THE ACTUAL CABIN TEMPERATURE RANGE FOR EACH FLYING SUIT COMBINATION IS INDICATED BY A BULB-SHAPED SYMBOL. THE BROAD FAT PART OF EACH "BULB" LIES OPPOSITE THE TEMPERATURES AT WHICH THE AVERAGE INDIVIDUAL WILL BE COMFORTABLE FOR THREE HOURS OR SO [ISSUE SHOULD BE BASED ON THIS RANGE ONLY]. THIS ASSUMES THAT HEAD, HANDS AND FEET WILL BE COMFORTABLY COVERED WITH ITEMS OF THE SAME THERMAL VALUE.

THE NARROW TOP TIP OF EACH BULB IS OPPOSITE THE WARMEST TEMPERATURES WHICH THE AVERAGE INDIVIDUAL CAN STAND IF VERY LITTLE UNDERCLOTHING IS WORN OR THE WIND IS STRONG. THE NARROW BOTTOM TIP OF EACH BULB IS THE TOO-COLD RANGE IN WHICH SOME "WARM-BLOODED" INDIVIDUALS MAY BE COMFORTABLE FOR A SHORT TIME OR IN WHICH NORMAL INDIVIDUALS MIGHT BE WARM FOR A SHORT PERIOD IF THEY ADD PLENTY OF EXTRA UNDER-

Figure 17 — Functional Thermal Ranges of Flight Clothing



LEGEND

This chart is of value in obtaining general information about the types of AAF flight clothing required at various altitudes and latitudes.

The Air Mass about the earth is divided into layers by lines of mean average temperatures. Lines shown identify temperature zones in degrees Fahrenheit as applied to AAF clothing. In the middle of each temperature zone, the clothing needed will be indicated. In the area bordering each division between zones either the heavier clothing above, or the lighter clothing below may be needed, depending upon day to day changes.

Figure 18 — Altitude Latitude Isotherms Showing Temperature Zones as Applied to Clothing

failure. The ground crews servicing such aircraft must wear special protective clothing.

SUPPLY OF OXYGEN

The production of oxygen as a gas or as a liquid in a mobile unit probably has been carried to its maximal development in the A-1 generator, which produces approximately 1100 cu ft of gaseous oxygen per hour. Refinements in the development of liquid oxygen, as well as use of the by-product nitrogen, will be the object of future study. This study will be made in conjunction with personnel of the Power Plant Laboratory, who will be interested in the use of the larger production, i.e., the liquid producing columns for projectile and aircraft power. These studies require continued liaison with the Massachusetts Institute of Technology, Cambridge, Massachusetts. Germany produced liquid oxygen on a large scale with apparatus similar to that employed by the United States Army Air Forces. Other physical processes for the separation of oxygen from the air will be found. Continued development on small airborne chemical generators for oxygen is indicated.

The design and development of a compact instrument for testing the purity and dryness of oxygen is to be continued. Present instruments are intricate and bulky. The studies made to date indicate that a simple apparatus can be designed in which the dewpoint method is used, with carbon dioxide as a refrigerant. Development of this type of apparatus can be implemented by liaison with the Arthur D. Little Company, Cambridge, Massachusetts, development engineers. This type of instrument will enable study to be made of the tolerable moisture content in aircraft oxygen systems.

Development of high-pressure cylinders (1800 psi or more) and of low-pressure cylinders (400 psi) will continue. The study will be directed toward providing a cylinder to reduce the weight required for volume of gas stored. The investigation will include metallurgical advances in the use of aluminum and magnesium and in the processing of these metals. The combat efficiency of German and Japanese aircraft was reduced because of their installation of cylinders that were shattered by 50-caliber ammunition gunfire. Design work on low-pressure cylinders had been indicated in both Germany and Japan. Large and small liquid storage tanks are under development. A 150-gal container now in use results in a saving in weight of approximately 8000 lb, when compared with conventional cylinders.

A complete and comprehensive program for studies on liquid oxygen has been formulated in the past year and the study will be continued to complete the project under this same plan. The use of liquid oxygen results in a saving in weight of approximately one-fifth, a saving in space of one-seventh or, expressed in ratio, 1 to 5 and 1 to 7, respectively (Figs. 19 and 20). Liquid-oxygen equipment under procurement for study includes storage equipment in various sizes; transfer or charging equipment, which involves the development of liquid pumpts; and mechanical heat-exchange type of equipment installed in aircraft. Developments in the German Air Force progressed along similar lines and corroborated work done by the United States Army Air Forces. The development of the aircraft system has involved advances from the old type copper vacuum container to a stainless steel type of container.

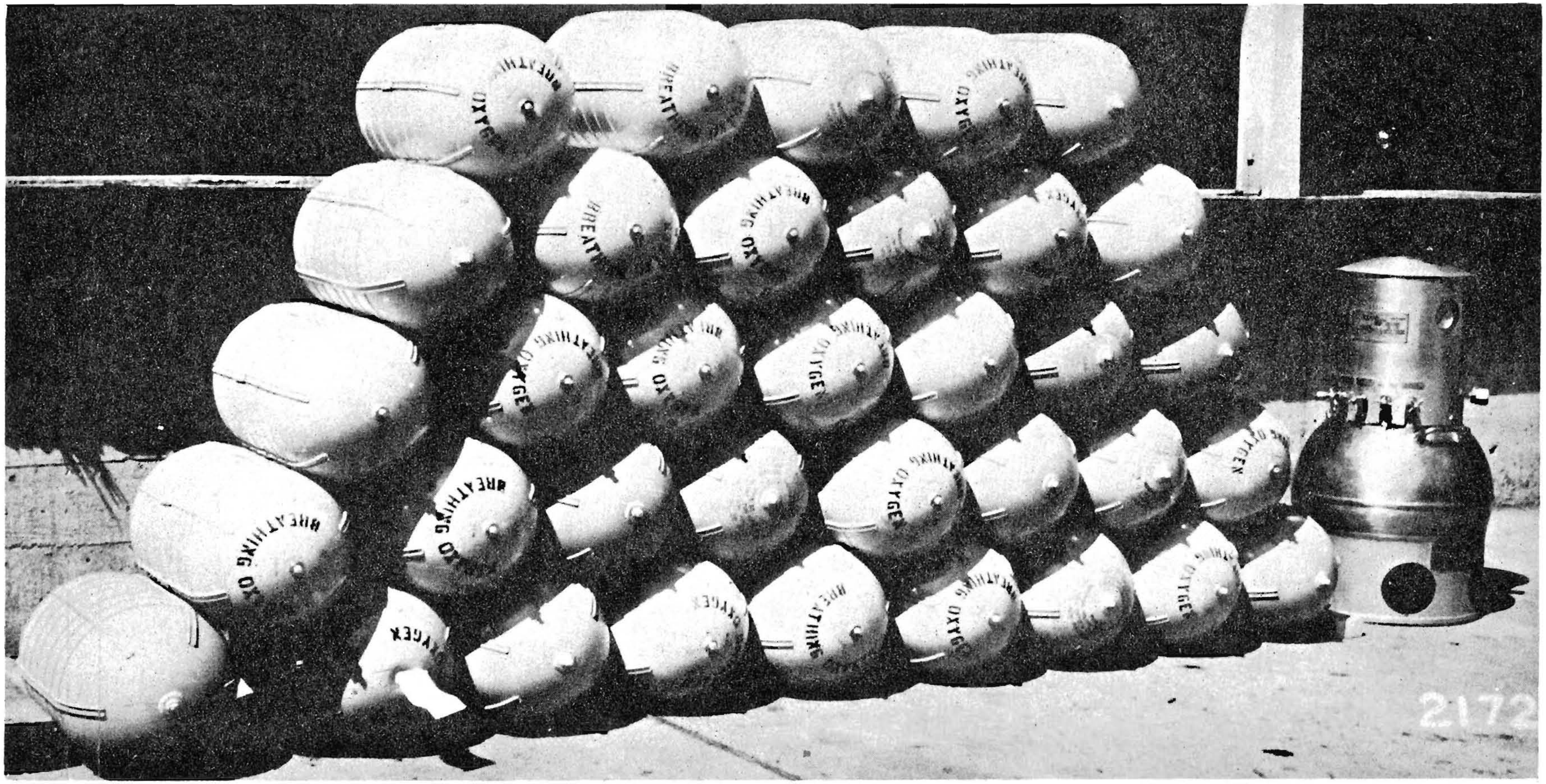


Figure 19 — Comparison of Storage Space Required by Gaseous and Liquid Oxygen Supply Systems for Aircraft

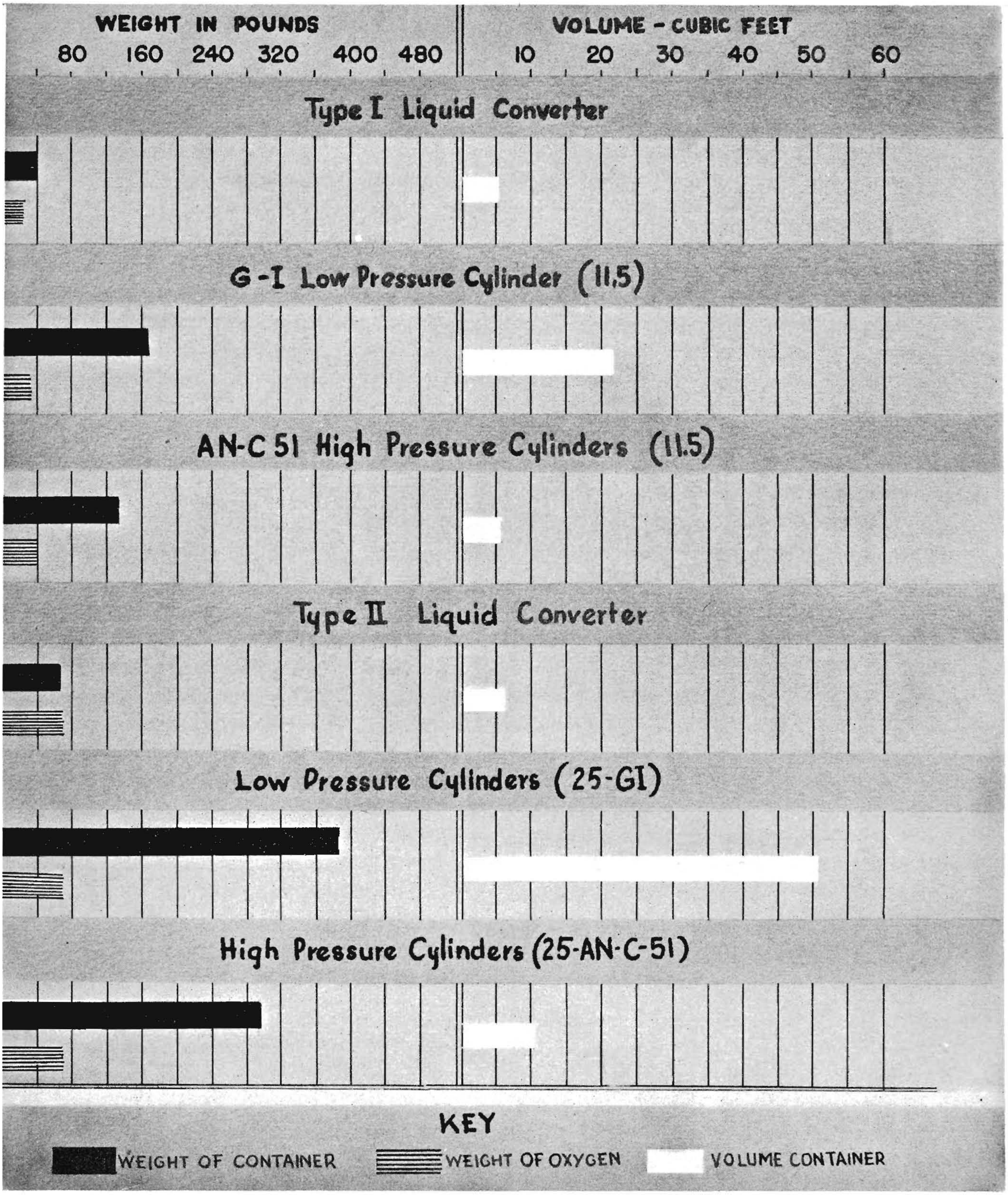


Figure 20 — Relative Weights of Gaseous and Liquid Oxygen Containers

Check valves are necessary to protect oxygen systems which are exposed to gunfire and filler valves to facilitate servicing. The major development in valves and fittings will be a spring-loaded check valve for use in the aircraft system. Refinement in hand valves and filler valves will be made as possibilities for improvement arise.

Installation procedures have been adequate generally, but in further study attention will be given to considerable detail and coordination with other laboratories involved. The relationship of oxygen equipment to hydraulic equipment, as far as the proximity of the respective tubing is concerned, has not been suitably settled.

OXYGEN DISPENSING EQUIPMENT

The key item of the oxygen system is the oxygen regulator, which takes the oxygen from the pressure that exists in the line and delivers it to the user. Design of this instrument has involved maximal application of basic physiologic requirements, and the principles of pressure regulation and gas flow. Ideally, development of demand type regulators will be centered on a regulator which will deliver the mixtures with automatic safety pressure and pressure breathing facilities for the convenience of flying personnel, and will combine in a single case the regulator pressure gauge and oxygen indicator as well as connections for the central warning panel. German development of demand regulators had fallen behind United States Army Air Forces development during the war. The Germans' use of a single design in the manufacture of regulators has an obvious advantage. Production of a poor copy of the German demand regulator for the Japanese Army Air Force had been underway for a year.

Continuous flow equipment, although considered obsolete by the Army Air Forces when the demand system was acquired, has proven to have specialized usage for passenger oxygen systems in cargo aircraft. Refinements in the continuous flow regulator will be continued to provide an individual automatic continuous flow regulator for the crews of pressurized cabin airplanes. This equipment will reduce by 75% the weight of the equipment now installed. The automatic regulator used by passenger systems will be redesigned so that one regulator can be used for the entire plane, whereas, at the present time, one regulator is required for every 10 persons. This will involve a reduction in weight of approximately 80% in the required regulator equipment in large aircraft. A correlated reduction in problems of installation and maintenance also will result. With modification of the outlet, this regulator also can be used in crew positions.

Further refinements of continuous flow systems for passengers may result in a very light, disposable mask which in many ways will improve the oxygen equipment.

The design of gages and indicators must be focused on the problem of reducing weight and improving performance. The combination indicator (flow indicator and pressure gage) now used by the Army Air Forces is large as compared to the German counterpart. This bulk is due to the existence of two current designs of the demand regulator (necessitated by heavy war production demands). Proposed development of regulators will eliminate this factor.

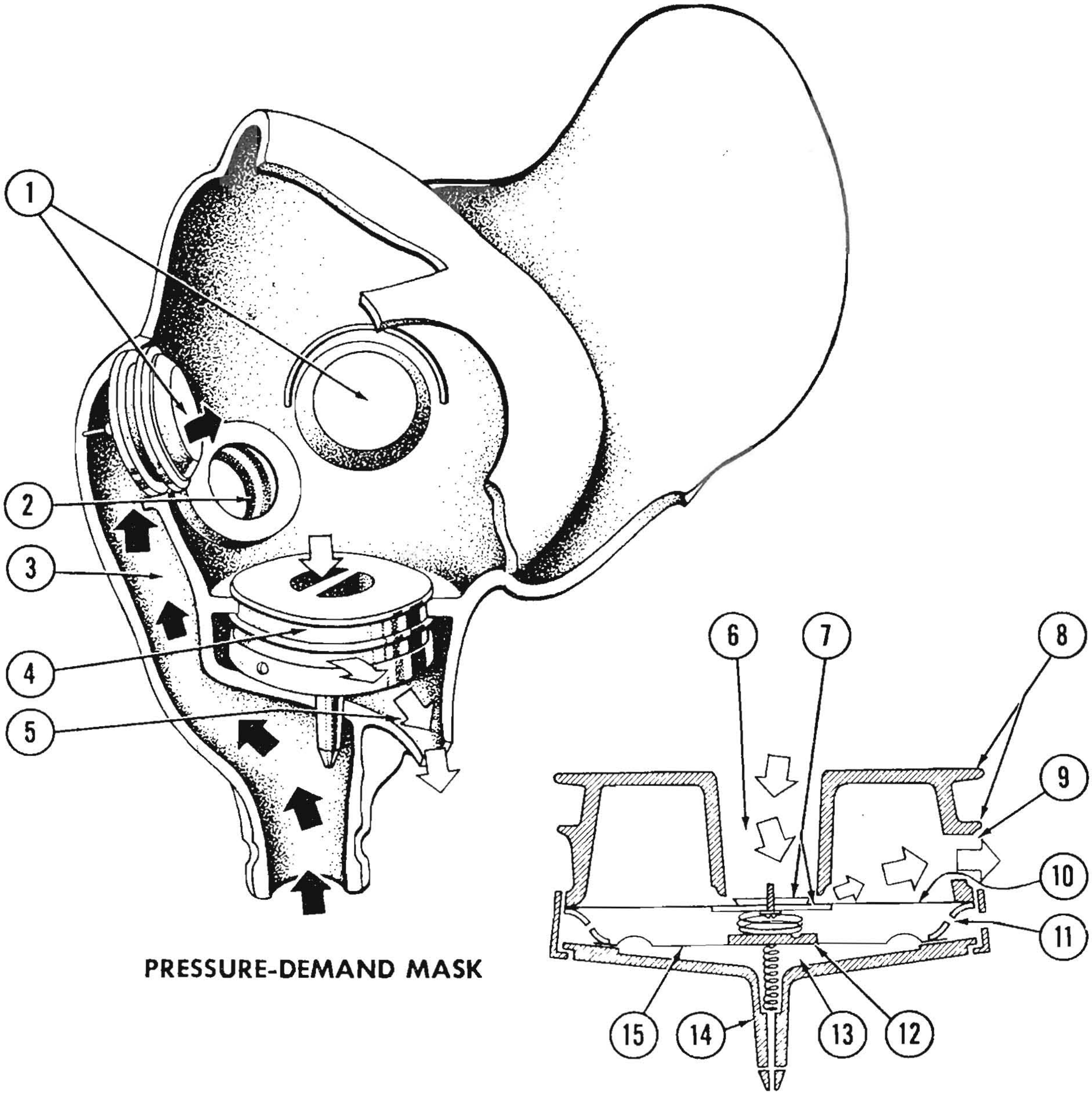
The current program of design of a central warning panel will provide an instrument which will inform a responsible crew member of the time at which it becomes necessary to use oxygen and also will inform the responsible crew member as to whether each member of the crew is using oxygen. The German and Japanese Air Forces had no similar development.

Designing of oxygen has been centered on the program of a universal mask, in three sizes, for the various types of equipment. The present demand (A-14) and pressure demand (A-13) masks are considered the best in use. The British H-mask is the only close competitor. German masks, although light and compact, were poor in fit. Major improvements to be made involve obtaining more comfort over a period of eight to ten hours as well as more nearly adequate fit and suspension. Designing of specialized masks for particular types of aircraft would provide a better solution to the problem of masks. Full-face masks (Fig. 21) may be necessary for bailing out at high speeds and from high altitudes.

The major new development now underway is to provide fittings and accessories to allow use of current bailout equipment in conjunction with the ejection seat. Further design is required to integrate the entire emergency gear with the ejection seat. The actual requirements for this type of equipment when used with the ejection seat in high-speed, high-altitude aircraft are not adequately known, and the second phase of design of this equipment will have to be preceded by accumulation of further physiologic data. Results of the extensive work done by the German Air Force on high-altitude bailout are questionable and must be checked. German Air Force oxygen bailout equipment was heavy (10 lb more than Army Air Forces equipment), and operated poorly at low temperature (−40°C). The oxygen bailout unit used in the Japanese Air Force was a copy of the first United States Army Air Forces unit designed in 1940. Modification of Army Air Forces equipment for the ejection seat likely will provide equipment superior in weight and performance. Further designs of emergency gear will be contemplated for use with the pressure suit.

As pressure breathing continues to show its usefulness in new and future jet-propelled aircraft flying at extreme altitudes, new methods for using and applying the principle of pressure breathing must be found. Diagrams of existing pressure-breathing equipment are shown in Figs. 22 and 23. At present the ceiling for continuous use of pressure breathing is 42,000 ft, with 6 in. of water pressure. With from 10 to 12 in. of water pressure, pressure breathing may be used as an emergency source of oxygen up to 50,000 ft. For periods of useful consciousness of two minutes or longer above 50,000 ft, some form of pneumatic clothing, such as an anti-g type garment combined with full face mask or helmet, or an emergency pressure suit, will be required to protect the pilot in the event of loss of cabin pressure. Intermittent pressure breathing is another method which has been shown to be practical for extremely high-altitude flights. Both the Japanese Army Air Force and The Japanese Navy Air Force had realized the need for pressure breathing since their standard oxygen equipment was inadequate above 30,000 ft, and had developed pressure-breathing helmets covering the entire head and neck. Flights had been made in the low-pressure chamber to approximately 46,000 ft, but the equipment was not nearly as well designed as that of the United States Army Air Forces and had not been flight tested to high altitude or combat tested. Investigation of German Air Force oxygen equipment reveals that pressure breathing had not been used at all. Conversations with German flight surgeons revealed at the time when hositilities ceased, they were considering the American equipment.

Figure 21 — Early Development of Full Face Oxygen Mask



PRESSURE-DEMAND MASK

EXHALATION VALVE DETAILS

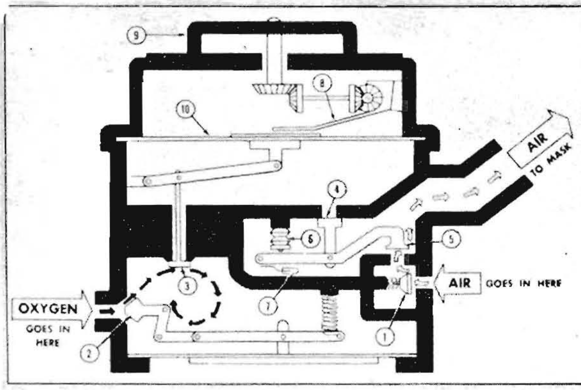
1. Inlet Valves
2. Recess for Microphone
3. Inlet Port to Mask
4. Exhalation Valve
5. Outlet for Exhaled Air

OXYGEN

EXHALED AIR

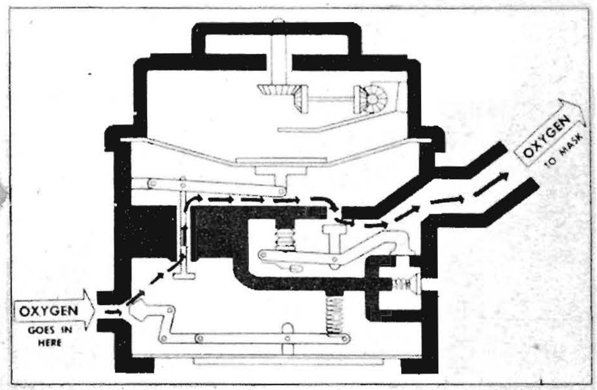
6. Exhaled air enter exhalation valve here
7. These plates stiffen the main diaphragm
8. Projections on valve housing which seat in mask
9. Exhaled air leaves the valve here
10. Main diaphragm
11. This port permits pressure between the two diaphragms to equalize with the outside atmosphere.
12. This cup holds hairspring in place between the two diaphragms
13. Oxygen supply pressure is exerted in this "compensating" chamber
14. This tube sticks down into the mask inlet
15. This "compensating diaphragm" responds to oxygen supply pressure by pressing up against the main diaphragm

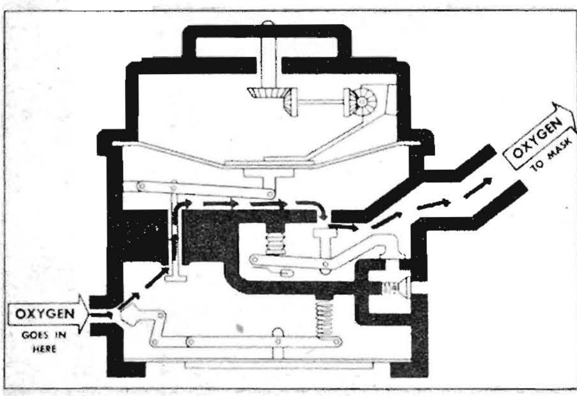
Figure 22 — The A-13 Oxygen Mask, Valved for Pressure Breathing



A-14 regulator operation during inhalation at sea level. Oxygen diluter valve (4) is closed; air diluter valve (5) is open, and you breathe air only.

Regulator operation during inhalation at 30,000 feet. Air diluter valve (5) is closed; oxygen diluter valve (4) is open, and you breathe 100 percent oxygen.





Regulator operation during inhalation with pressure breathing. Spring (8) presses down on diaphragm, opening demand valve (3) and forcing oxygen into the mask under pressure.

Regulator operation during exhalation with pressure breathing. As you exhale you momentarily raise the pressure in the mask above the oxygen supply pressure, forcing the diaphragm up against the spring tension. The demand valve (3) closes and no oxygen flows.

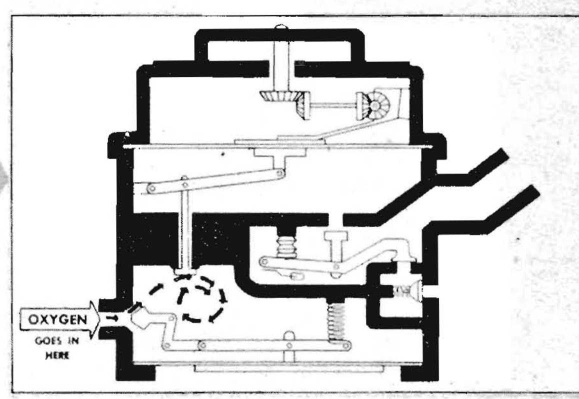


Figure 23 — Operation of the A-14 Pressure Demand Regulator

One essential factor in the development of oxygen equipment is to produce units that will perform properly under conditions of extreme cold. One device used for this purpose is the breathing head illustrated in Fig. 24.

PRESSURE SUITS

At present it appears that aircraft capable of routine operation above 50,000 ft will be powered by the rocketjet or by the turbojet, using fuels containing oxygen in some form. For pilots and crewmen in these types, a pressure demand oxygen system will be satisfactory, since our present equipment is adequate in emergencies up to 50,000 ft. For the present, flights above 50,000 ft and well into the stratosphere, an emergency pressure suit will be required for use in the event of accidental loss of cabin pressure. This pressure suit, in addition to its use as emergency equipment in pressure-cabin airplanes, will meet problems of bodily comfort in that it can be ventilated continually and will allow the use of high-pressure differentials in pressure cabins. A liquid oxygen supply for pressure suits has been designed. German data on pressure suits have been reviewed extensively. The chief development in pressure suits will center about the use of new, lighter materials. A Wright Field pressure suit is shown in Fig. 25. The use of shoulder harness at high altitudes is advisable as it prevents the pilot from falling forward on the controls in the event of unconsciousness resulting from anoxia or injury.

INTEGRATION OF ARMY AIR FORCES FLYING ASSEMBLY

During the past war, one of the great weaknesses of a complete Army Air Forces flying assembly for aircrews was poor integration of the various items of equipment which required attachment of the crew member to the airplane. These items of attachment included radio connections to the heated suit and microphone, the cord for the electrically heated suit and the oxygen connections. These items in current equipment are served by four separate cords, or tubes, which can be located at definite and remote attachments in the airplane. A development program should be initiated immediately to devise methods of simplifying and combining these functions into a single cable that can be quickly disconnected. An attempt in this direction was made during the war with the cooperation of the General Electric Company, but the item was bulky due to the attempt to integrate and use existing equipment.

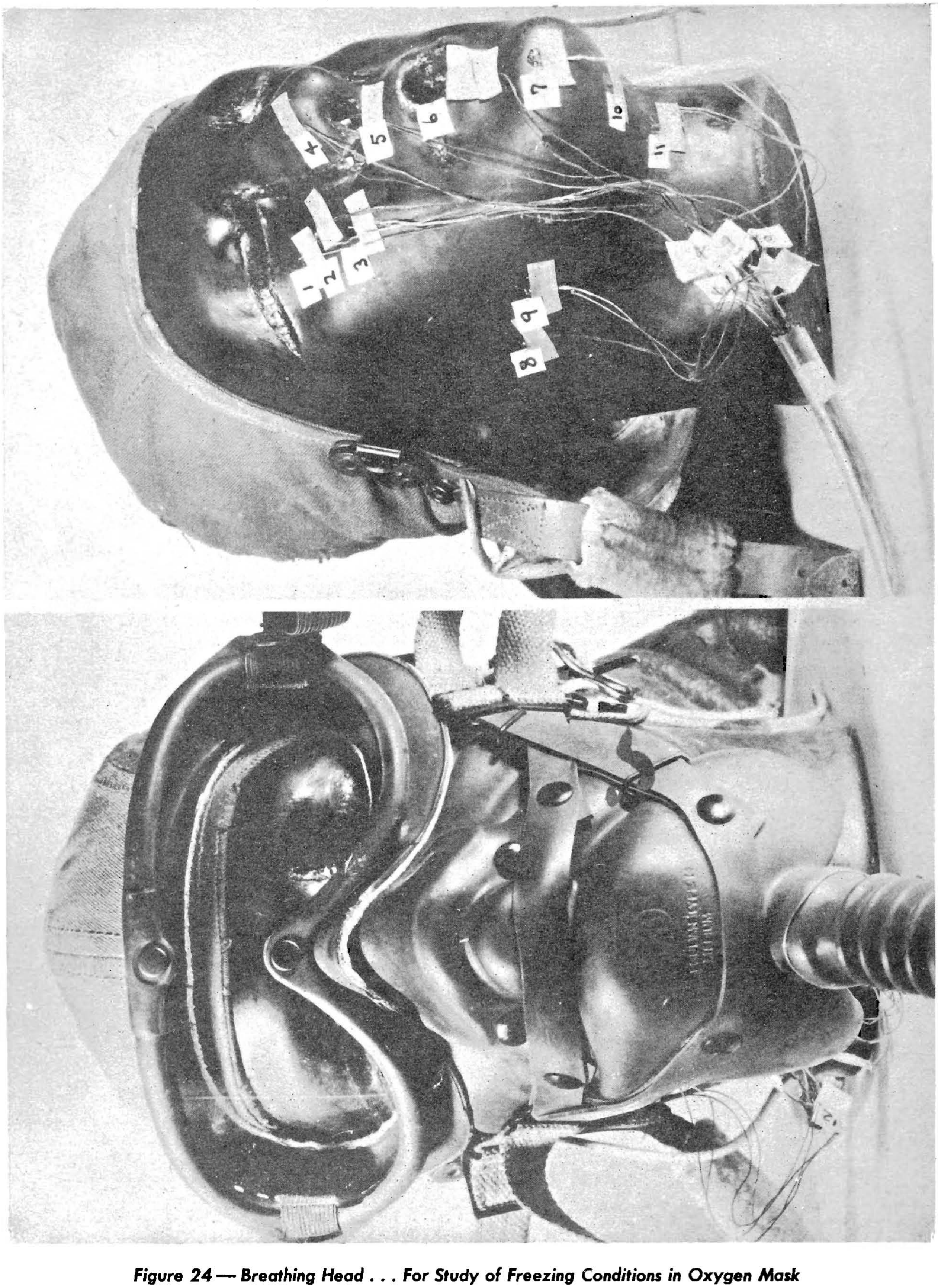


Figure 24 — Breathing Head . . . For Study of Freezing Conditions in Oxygen Mask

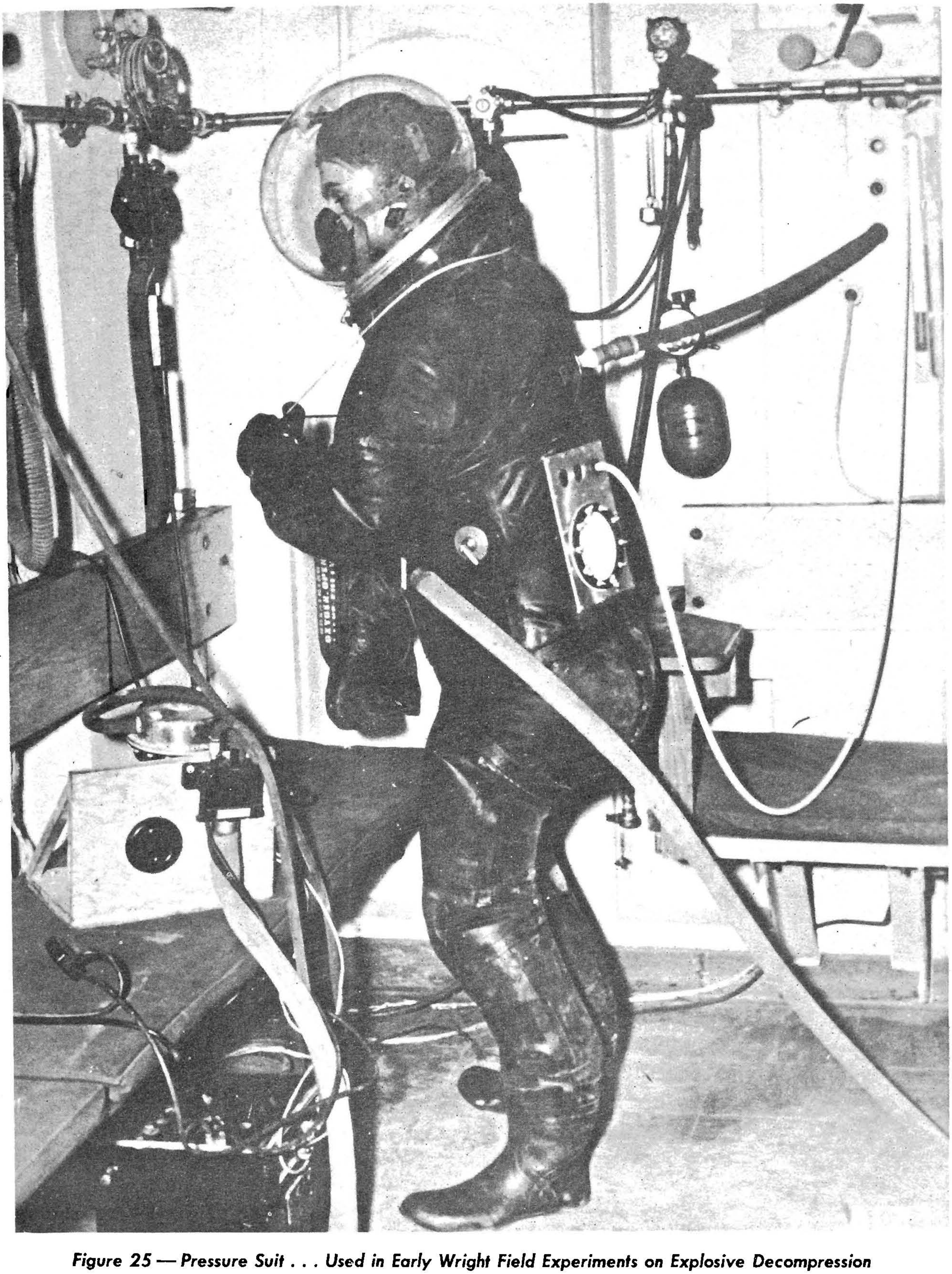


Figure 25 — Pressure Suit . . . Used in Early Wright Field Experiments on Explosive Decompression

AERO MEDICAL RESEARCH IN AIRCRAFT DESIGN

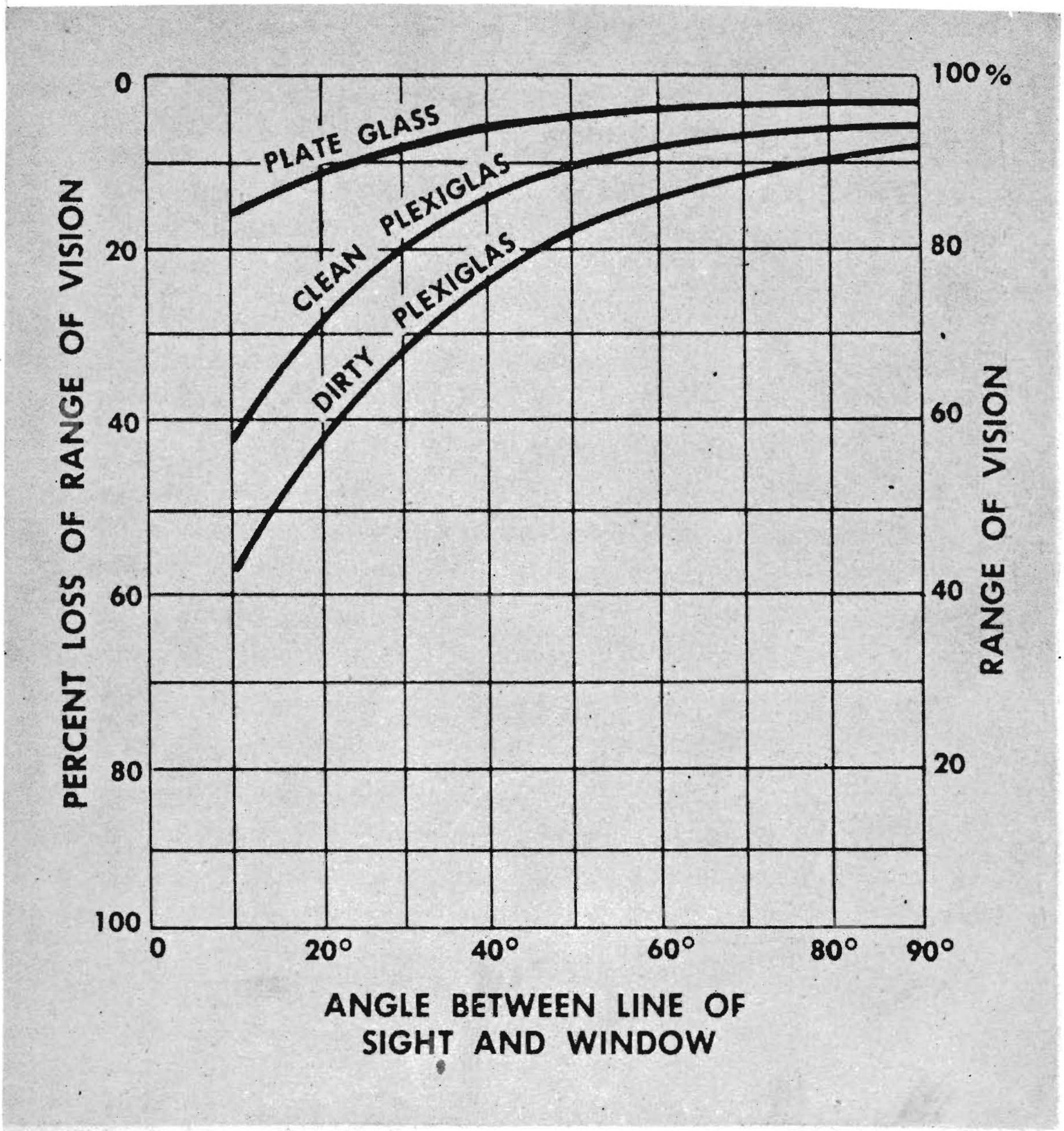
The war just ended has shown to Americans and Germans, independently, the necessity of medical advice in aricraft design. Further advances in capabilities of aircraft, which impose a smaller margin between psychophysiologic requirements and human tolerance, call for even greater refinements in operational efficiency of newer aircraft. This places a responsibility on the Army Air Forces Medical Services for applying basic physiology, biology, biophysics, pathology and psychology in the development of specifications and requirements for structure of aircraft. The more quickly a course in human engineering can be established as a part of the course in aeronautical engineering at universities and at institutions such as the California Institute of Technology and the Massachusetts Institute of Technology, the more quickly will the human be integrated properly with aircraft design.

VISION THROUGH WINDSCREENS

As speeds of aircraft increase, use of plate glass of high optical quality, as is customary in conventional aircraft, becomes undesirable because of its poor aerodynamic qualities. The present tendency is for all high-performance aircraft to use formed plastics (plexiglas) for windscreens and sighting domes. The optical quality of formed plastics at present is not as good as that of grade B glass (Fig. 26). Poor optical quality will result in loss in range of vision by aircrews, loss in perception of depth, and loss in transmission, all of which affect efficiency of pilots. In the future, it is essential that manufacturers of plastics improve the optical quality of their plastic windscreens. At the same time, minimal allowable requirements for optical quality must be laid down to guide this development. Minimum restrictions in the field of vision in cockpits and combat stations means maximum effectiveness of crew and appreciably decreases the chance of being intercepted by surprise. The German Air Force has sponsored the development of curved bullet-proof plate glass.

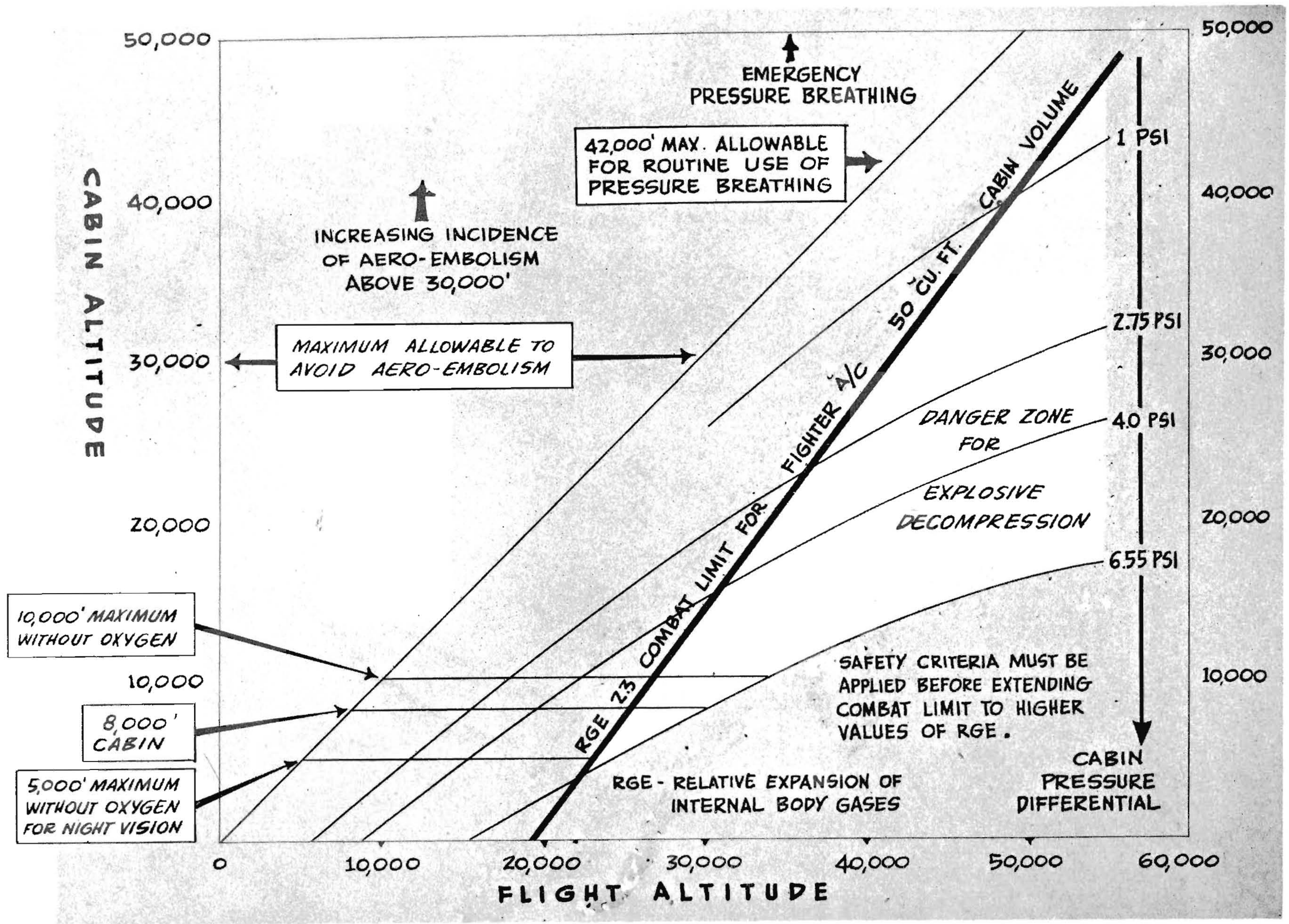
CABIN PRESSURIZATION AND EXPLOSIVE DECOMPRESSION

Use of troop-carrier aircraft of large capacity will be of increasing importance in the future. All such aircraft (the new C-97 for instance) are pressurized. The aero medical aspects of cabin pressurization are presented in Fig. 27. Use of cabin pressurization, although it eliminated the requirement for a first line oxygen system, imposes severe limitations on ventilation and temperature control in these types of aircraft, as the outside ventilation is less than 4 cu ft per person without supplementary recirculation and air conditioning. Flight data on large passenger loads in pressure-cabin aircraft are almost nonexistent. The largest recorded load is 106 passengers on a seven-hour flight in an XC-97 aircraft. In the future, twelve-hour flights can be considered routine; this factor also will introduce the problem of feeding people while in flight. A discussion of cabin pressurization as it is applied to military and commercial aircraft is presented in the Appendix. The German Air Force stopped most of their



RANGE OF VISION THROUGH GLASS, AND CLEAN AND DIRTY PLEXIGLAS AT VARIOUS ANGLES OF INCIDENCE. (OLENSKI AND GOODDEN.)

Figure 26 — Vision Through Windscreens


CABIN ALTITUDE
FLIGHT ALTITUDE
0
10,000
20,000
30,000
40,000
50,000
60,000
EMERGENCY PRESSURE BREATHING
42,000' MAX. ALLOWABLE FOR ROUTINE USE OF PRESSURE BREATHING
INCREASING INCIDENCE OF AERO-EMBOLISM ABOVE 30,000'
MAXIMUM ALLOWABLE TO AVOID AERO-EMBOLISM
10,000' MAXIMUM WITHOUT OXYGEN
8,000' CABIN
5,000' MAXIMUM WITHOUT OXYGEN FOR NIGHT VISION
RGE 2.3 COMBAT LIMIT FOR FIGHTER A/C 50 CU. FT. CABIN VOLUME
1 PSI
2.75 PSI
4.0 PSI
6.55 PSI
DANGER ZONE FOR EXPLOSIVE DECOMPRESSION
SAFETY CRITERIA MUST BE APPLIED BEFORE EXTENDING COMBAT LIMIT TO HIGHER VALUES OF RGE.
RGE - RELATIVE EXPANSION OF INTERNAL BODY GASES
CABIN PRESSURE DIFFERENTIAL

development of pressure-cabin aircraft in 1942 and never produced pressurized aircraft of large size (but no doubt they were contemplated). The Japanese had flight tested the Ki-108 in which the pressure in the cocoon-type cockpit was maintained at 8200 ft at an actual altitude of 29,500 ft. There was trouble with the cabin compressor in the few Japense pressure-cabin aircraft that were tested and the controls were far inferior to those used on the B-29. Associated with this same problem are studies on the required cabin environmental condition for the care of wounded during air evacuation. Special consideration must be given to removal of odor, low isobarics (3000 ft or lower) and constancy of cabin pressures during climb and descent.

The physiologic and medical problems associated with environmental temperature can be divided into the following categories: (a) the interacting climatic stresses of temperature, air movement, humidity, and solar radiation which tend to cool or heat the human body; (b) the physical and physiologic mechanism concerned in body temperature regulation; (c) the acclimatization processes; and (d) the utilities of clothing and other devices which aid in combatting climatic stress.

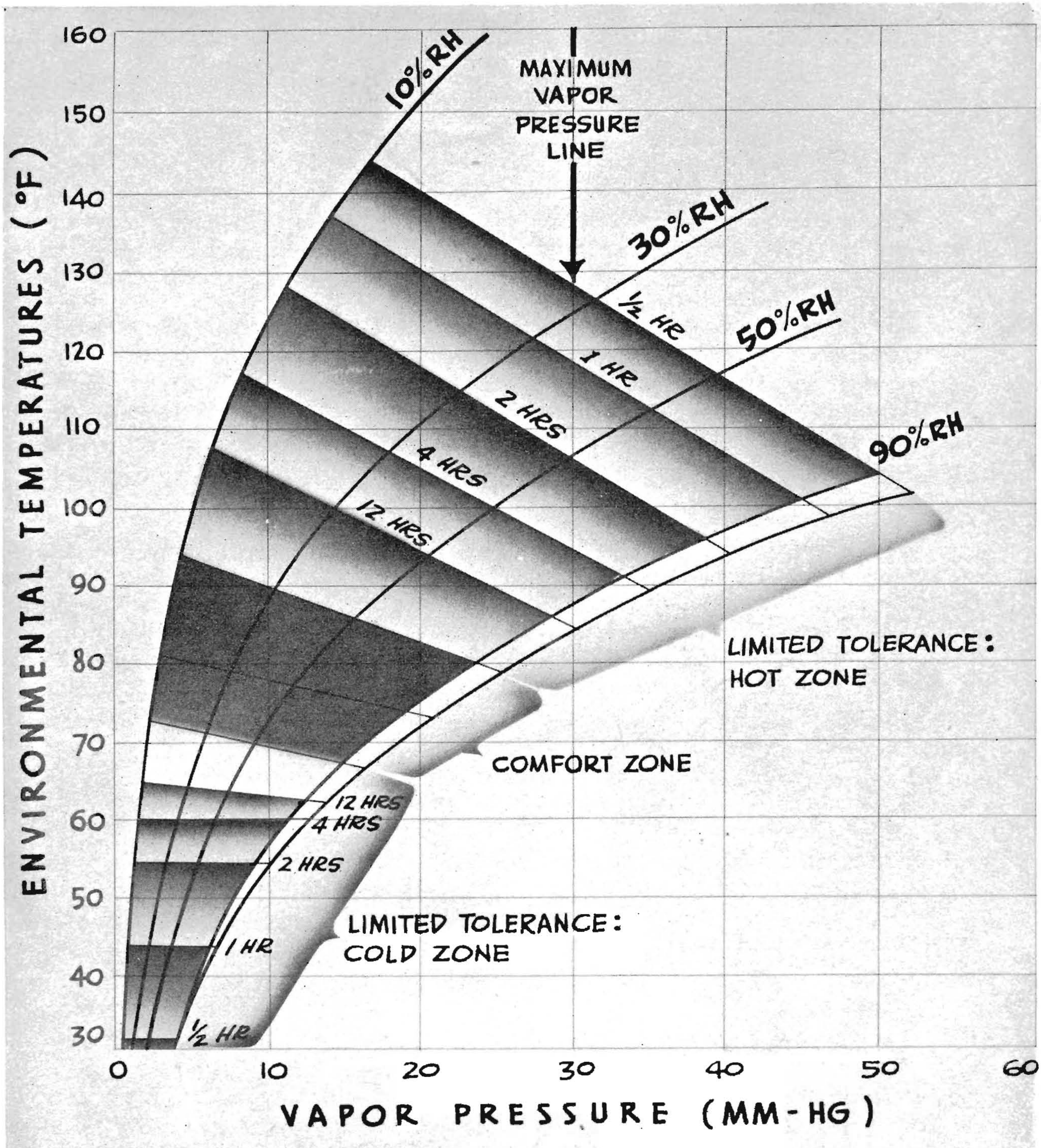
Any consideration of thermal requirements from the standpoint of tolerance and comfort in aircraft must be based on the degree of humidity in the cabin of the aircraft. In ventilation practices for aircraft, the wet-bulb temperature and relative humidity have proved of little value to the practical engineer. The most significant value is the actual vapor pressure expressed in millimeters of mercury. Therefore, the two primary independent variables describing any environmental condition are the temperature and vapor pressure. The third air movement, for the purpose of analyzing comfort, can be considered constant at approximately 20 cu ft/min. The zones of comfort and tolerance for the temperature spectrum normally met in passenger and jet-type aircraft are indicated in Fig. 28.

The experience of this laboratory to date shows that no danger from explosive decompression exists when the following conditions are satisfied:

$(Pc - 0.91)/(Pa - 0.91)$ shall be equal or less than $2.1 + 3.8\ (Va/A) \sqrt{(Pc - Pa)/Pa}$

where Pc = Cabin pressure before decompression in psi
Pa = Ambient or final pressure after decompression in psi
Vc = Volume of pressurized cabin in cu ft
A = Cross-sectional area of hole caused by structural failure or combat damage in sq in.

Data derived in this country on explosive decompression in relation to human subjects when compared with those from the German Air Force, indicate comparable degrees of allowable safety, especially for decompression in which the relative expansion of gas is in the range of 3.3 to 4.0 times, and the time of decompression is of the order of magnitude of 0.1 sec. The German data did not cover cases in which the relative gas expansion was approximately two and in which the decompression times were 0.005 sec. Since A (area of opening in square inches), above, is the unknown in all new aircraft, gunfire tests to determine the largest opening, A, should be done routinely.



Environmental temperature is the resultant of air temperature, wall temperature, and effective solar radiant temperature. It is assumed (a) that personnel are sitting and doing no more than light manual work, (b) that standard temperate climate clothing (one clo) is worn, and (c) that air motion is the equivalent of 200 FPM linear velocity. The tolerance lines give the recommended maximum duration of exposure to the stated conditions.

Figure 28 — Thermal Requirements for Tolerance and Comfort in Aircraft Cabins

SIZE OF INTERIORS OF AIRCRAFT

During the recent war, the importance of proper size was impressed on designers of all flying equipment. From known anthropometric data determined by measurements on several thousand flyers, it was possible to develop a standard scale of sizes for Army Air Forces clothing from which the probable numbers required in each size could be predicted. Standards for head size are essential in order to design and produce the proper equipment for the head (Fig. 29). Thus, surplus and short stocks of odd sizes were carefully avoided. Turrets and cockpits were made in sizes for optimal comfort and optimal flying efficiency for the largest number of flying personnel. Plastic mannikins manufactured to scale are an essential part of this program (Figs. 30 and 31). Safety of flying personnel also has been enhanced by consideration of the dimensions, location and accessibility of provisions for escape (Fig. 32). Oxygen masks were designed to fit the complete range of Army Air Forces standard faces (Figs. 33 and 34). Work of this type must be continued in the future. It is interesting that German Air Force criteria for cockpit seating in fighter aircraft, although independently reached, presented almost identical conclusions to those developed by the United States Army Air Forces. The present project is a continuous routine, but is important as a consideration in all flying equipment in which a human operator is concerned. A thorough research program should be carried out to determine the utility of anthropologic characteristics, in conjunction with psychologic and physiologic tests, in the selection and differential training of flyers. There are indications that useful relationships may exist. Future emergencies may not permit the waste of time and personnel involved in attempting to train unsuitable flyers. Two sets of basic data are available for such a study as regards suitability for military aviation, i.e., the various Army Air Forces surveys, enabling the anthropologist to furnish the aeronautical engineer information on the size and shape of the human body and on the nature and range of normal movements, and the series collected at the School of Aviation Medicine. Participants in both these studies are eager to complete the work by relating the data to the flyers' subsequent military records.

Further studies should explore the relation of physique to motion sickness, g tolerance, altitude tolerance, fatigue, and other physiologic reactions.

1. *Seat Comfort.*

One of the most important subjects of aero medical interest, but one which has received little attention, is seat comfort. The importance of this factor was first shown during the long-range fighter operations of the spring of 1944, over Europe, in which fighter pilots had to remain seated for as long as from 8 to 10 hr.

The Aero Medical Laboratory of Wright Field has undertaken a comprehensive study of seat comfort, using the universal test seat illustrated in Fig. 35. With this seat, every factor associated with elevation and tilt of the seat can be changed and various seat pressures over the body can be reproduced. In this study, it was demonstrated that the most important factor that fixes the space requirement for comfort in the cockpit of a fighter plane is the vertical distance from the line of sight (to the gunsight) to the floor level at the heel. The present Army Air Forces "Handbook of Aircraft Design" set a figure of 39 in. for this requirement. In the Wright Field studies it was demonstrated that it was not necessary to limit all cockpit arrange-

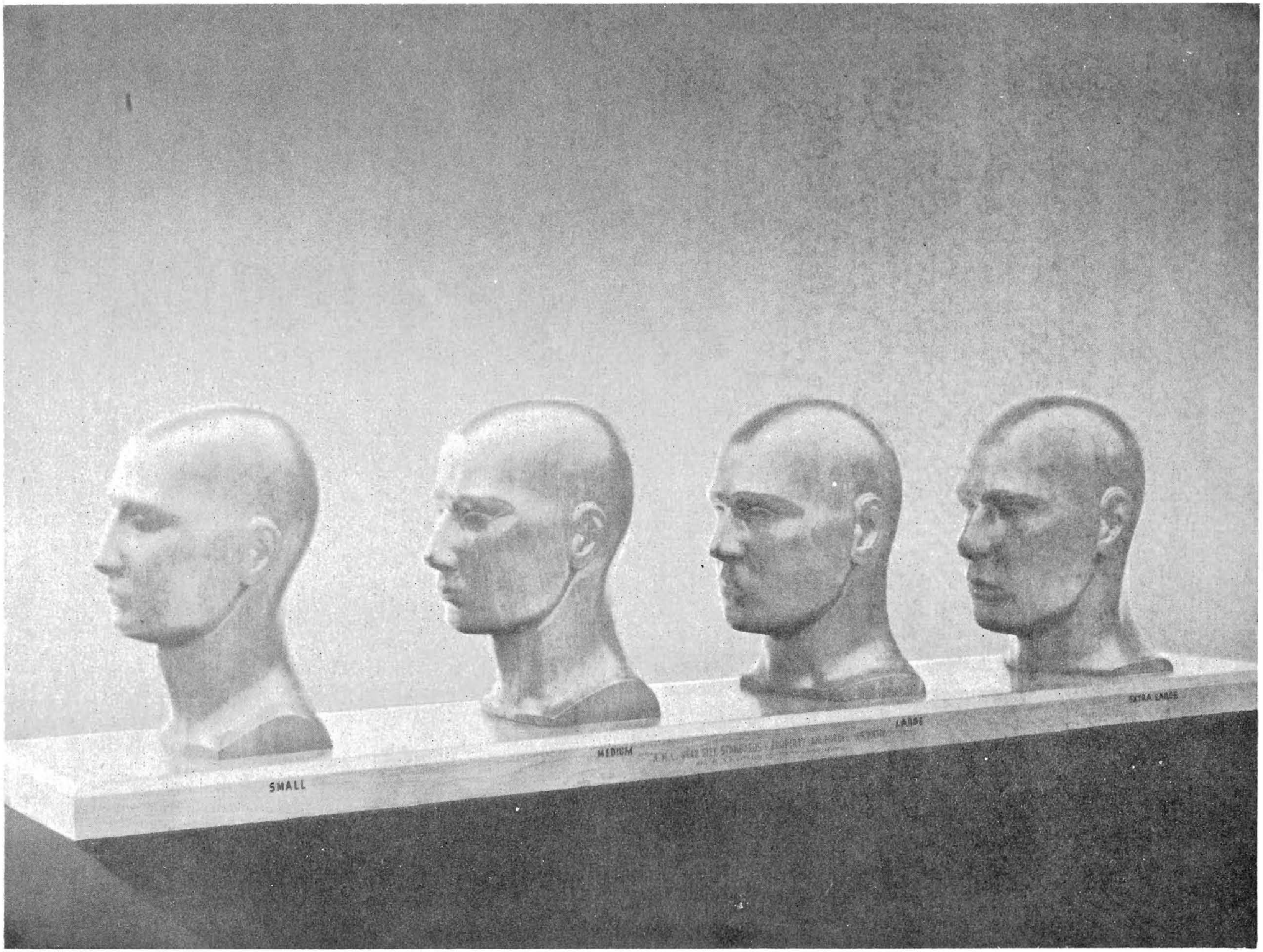
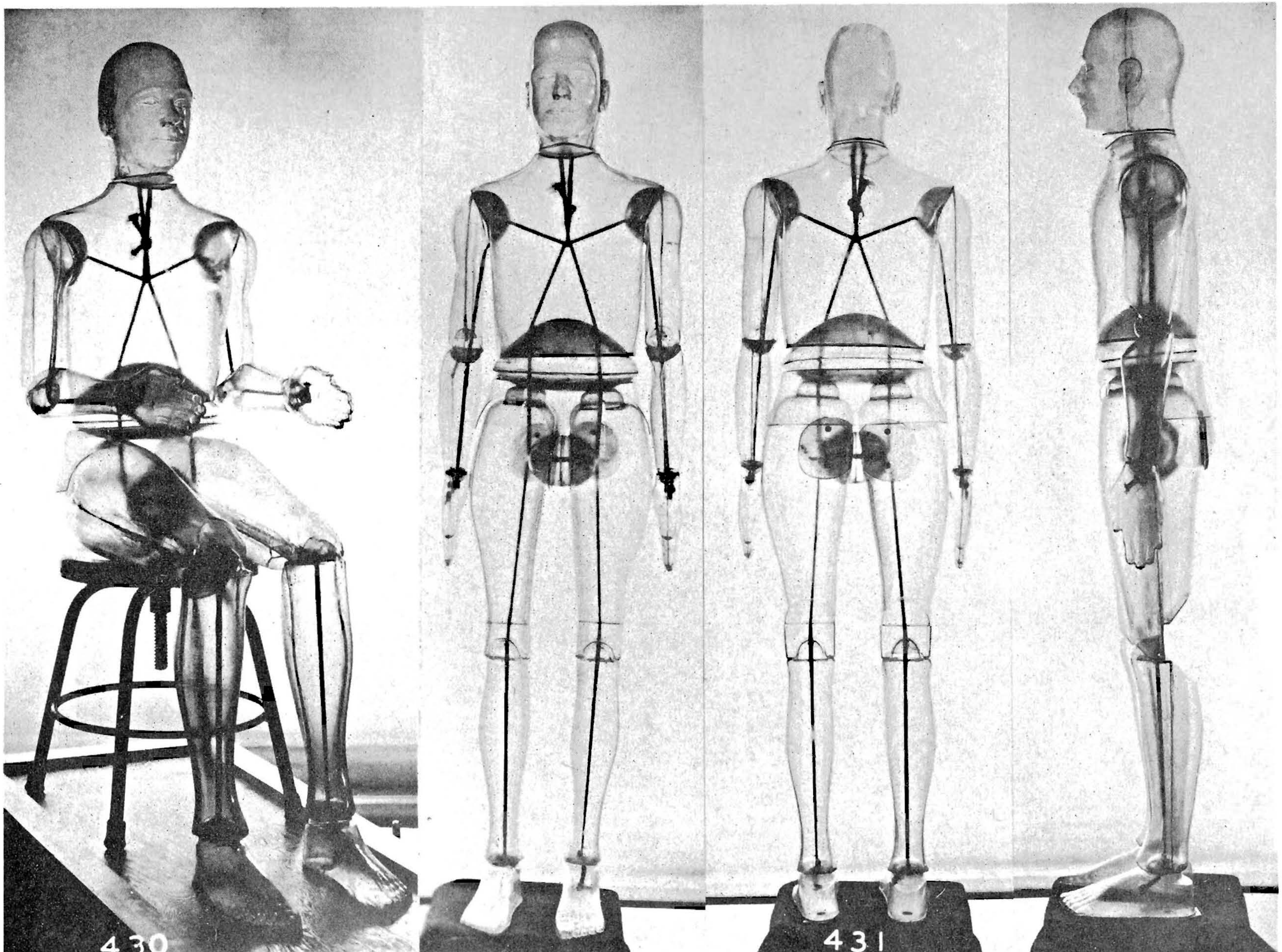
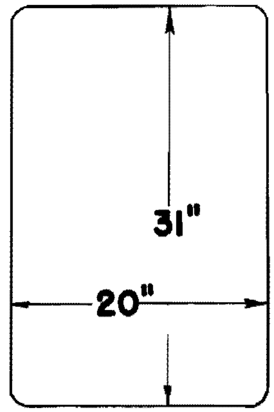


Figure 29 — Standards for Head Sizes in AAF

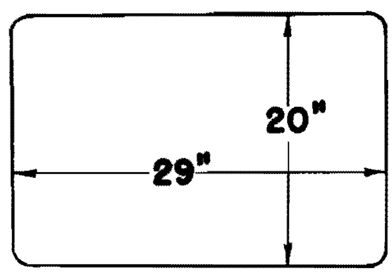


Figures 30 & 31 — Articulated Manikin . . . for Top 5% of AAF Personnel



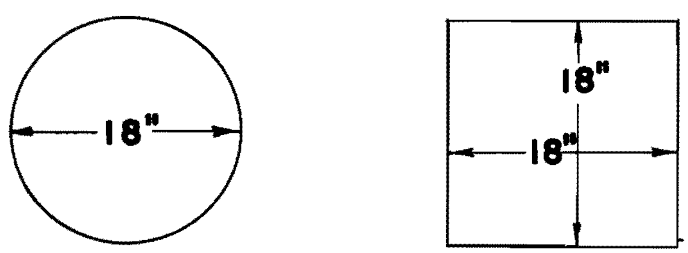
SIDE HATCH

FULL EQUIPMENT INCLUDES—FLYING CLOTHES, EMERGENCY (C-1) VEST, LIFE VEST, AND CHEST, BACK OR SEAT-TYPE PARACHUTES.



BELLY HATCH

FULL EQUIPMENT INCLUDES—FLYING CLOTHES, EMERGENCY (C-1) VEST, LIFE VEST AND CHEST, BACK OR SEAT-TYPE PARACHUTE.



TOP DITCHING HATCHES

FULL EQUIPMENT INCLUDES—FLYING CLOTHES, EMERGENCY (C-1) VEST, LIFE VEST AND DINGHY.

Figure 32 — Minimum Sizes and Optimal Shapes for Escape Hatches

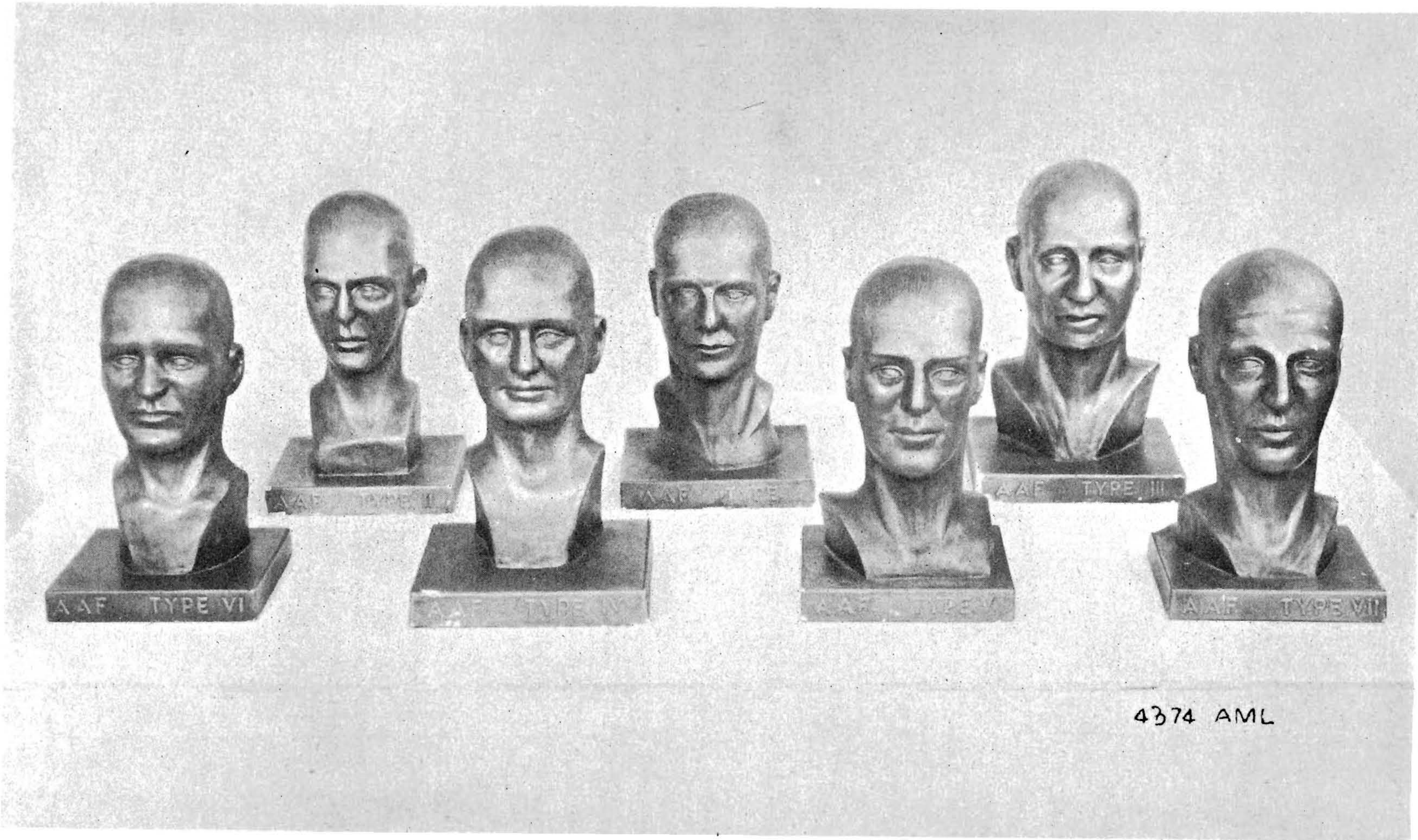


Figure 33 — Standard Faces

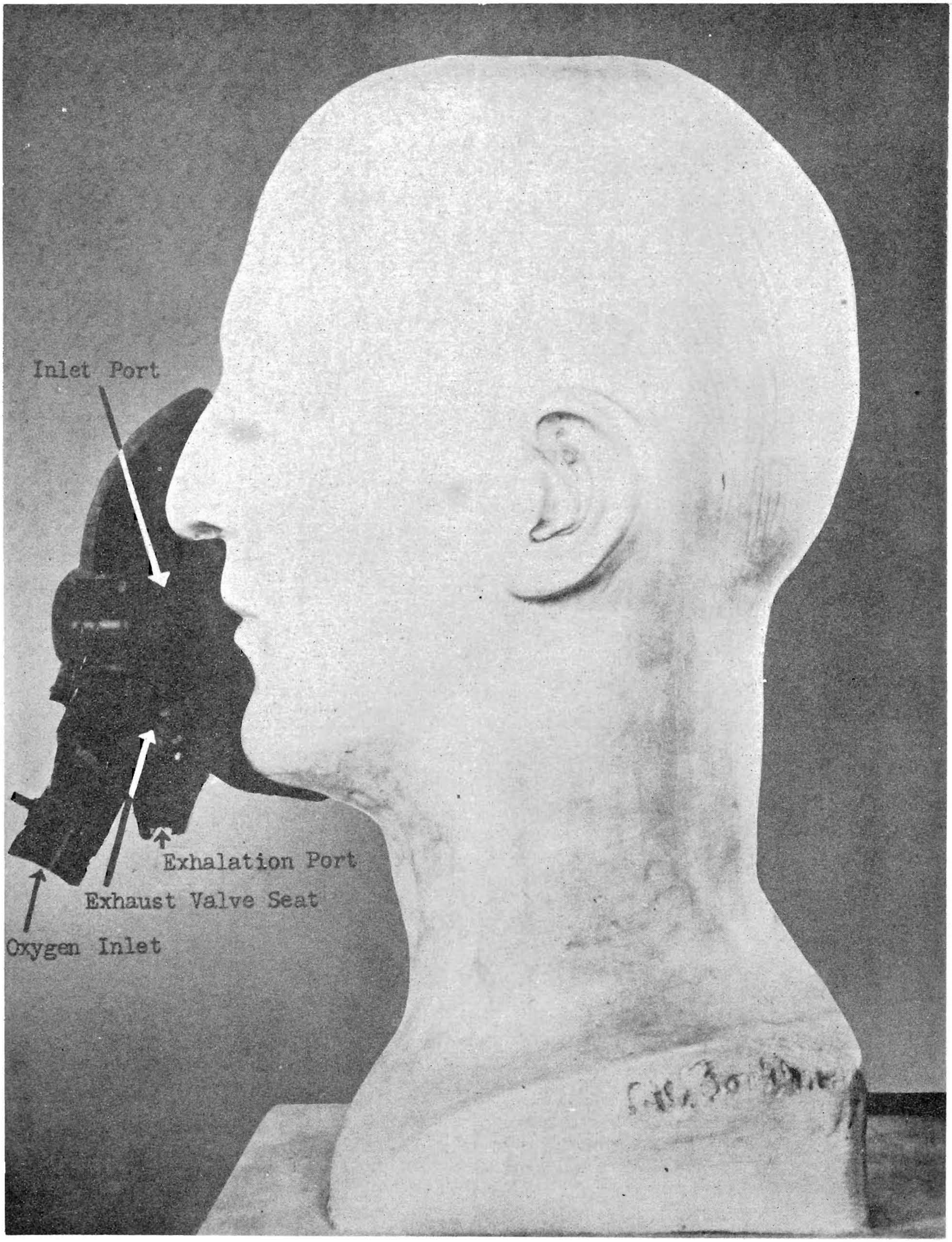


Figure 34 — Fit of Oxygen Mask on Face

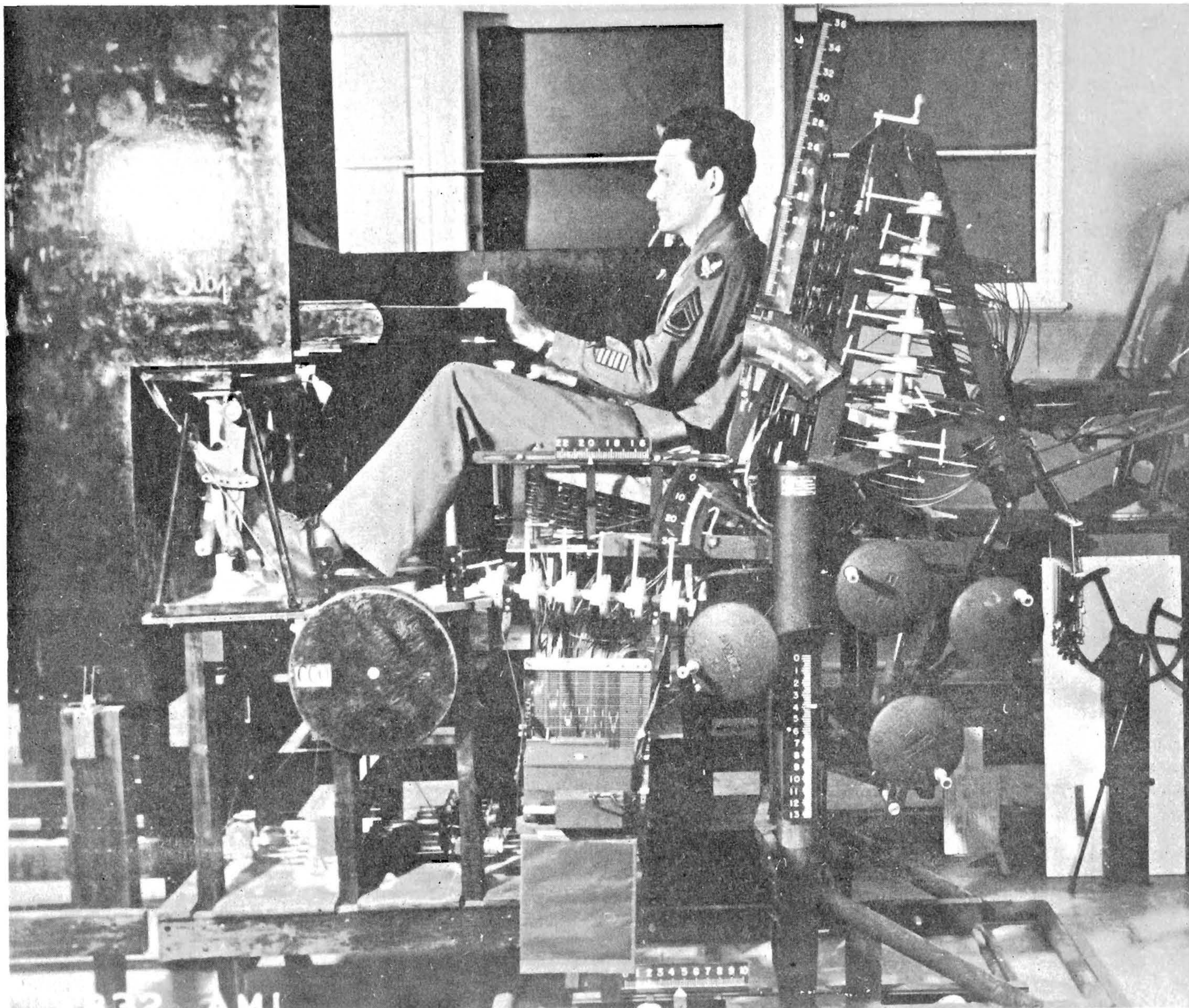


Figure 35 — The Universal Test Seat

ment to this 39 in. critical distance but it was possible to get a comfortable configuration for any eye-line to heel vertical distances. The results of those studies are shown in Figs. 36 to 41 inclusive, for various heights from 35 to 41 in. The configurations illustrated represent ideal seat comfort as tested on the universal seat.

2. *G Tolerance.*

Acceleration studies to date indicate that man's highest natural g tolerance (10-12 g) is obtained as he lies prone. With the increased possibility that guided missiles will be used in the future against piloted aircraft, evasive maneuvers exerting 8 g or more on the pilot are well within the realm of possibility. For the above reasons, it is extremely important that studies on the prone position be continued. Preliminary studies on flying comfort and efficiency in this position indicate that support of the head is the greatest problem. The Germans have used a chin cushion which is reasonably comfortable up to 5 g. Recently the University of Southern California has developed a head harness supported by a counterweight over a pulley. As the g increases, the force of the counterweight automatically increases and allows the pilot continuous free movement of his head during g pull-out. At present, the only Army Air Forces aircraft in which the pilot lies prone is the XP-79. Tests on this aircraft should be closely followed by all interested aero medical organizations.

3. *Controlling Forces.*

The amount of force necessary to operate the various controls of aircraft should be standardized. Although some airplane controls required exertion of a great deal of strength for their manipulation, no measurements of required muscular strength ever have been made. Selection of pilots from the standpoint of physical fitness has been based on height and weight. Meeting these two qualifications is supposed to fit them to meet unknown conditions. Somehow they meet these conditions, mostly because of the ingenuity of the pilots, who learn to use both legs, for example, when the strength of one is not sufficient. It would be more logical to measure maximal forces, optimal forces and forces associated with the utmost precision at which the pilot could operate the various controls. From these data, designers of aircraft should build efficient controls.

Other control research to be carried out in conjunction with the above study would include: the determination of flight control pressures that provide the greatest accuracy of "feel of controls;" determination of the relation between accuracy of location, discrimination and the spatial arrangement of aircraft controls, and development of tests for the evaluation of aircraft-type controls utilizing performance on a compensatory pursuit task.

Physical tolerance of pilots should be determined in order to select those pilots most suited for particular types of aircraft, or to allow institution of physical training to make them more efficient.

4. *Deceleration.*

At present, there are available only extremely limited data on the effectiveness of aircraft equipment and design from the standpoint of preventing injury by aircraft crashes. It is proposed to study these forces by means of catapults and other devices and

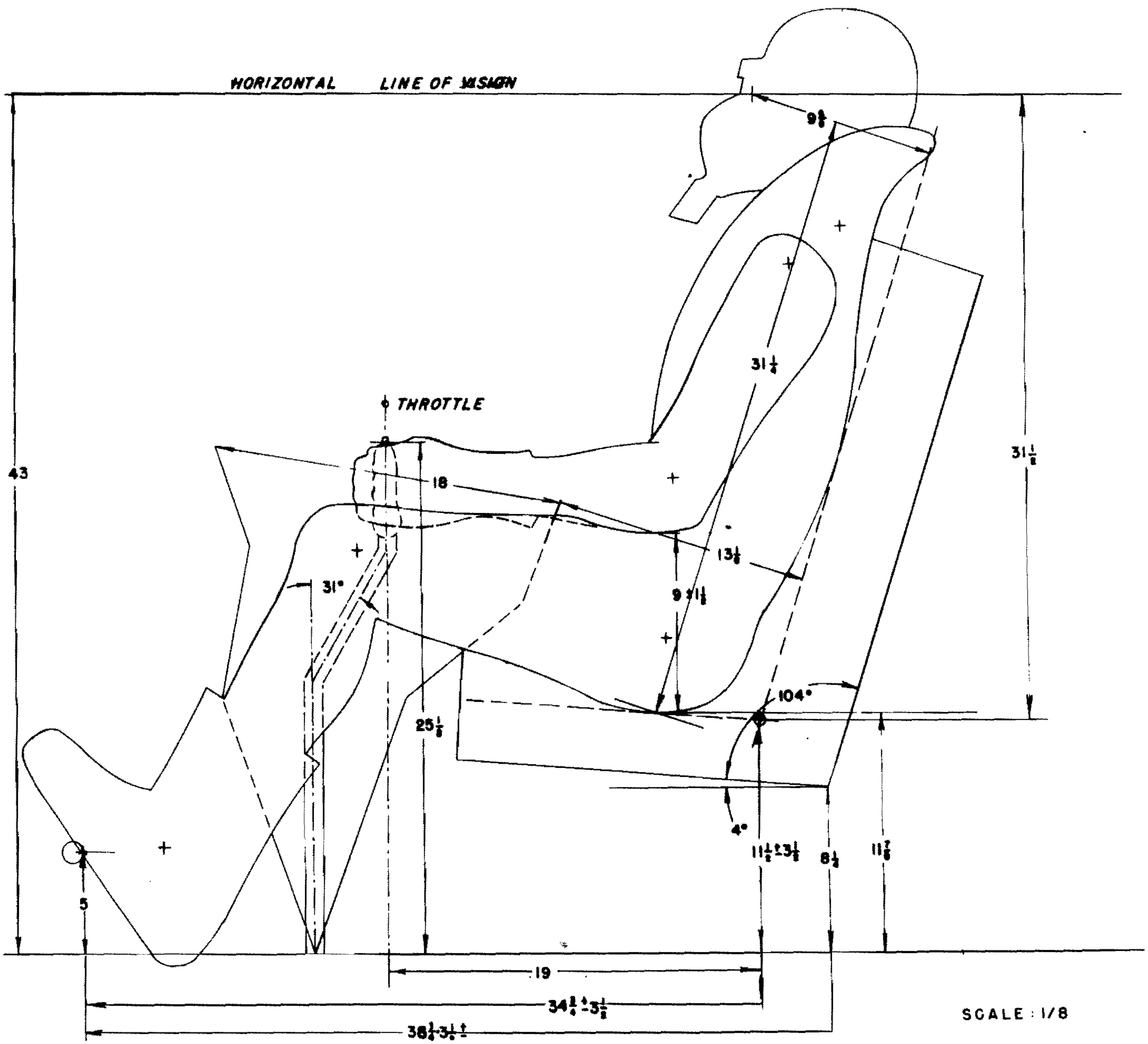


Figure 36 — Average Position of Seat in 43-in. Cockpit A.M.L. Test Seat

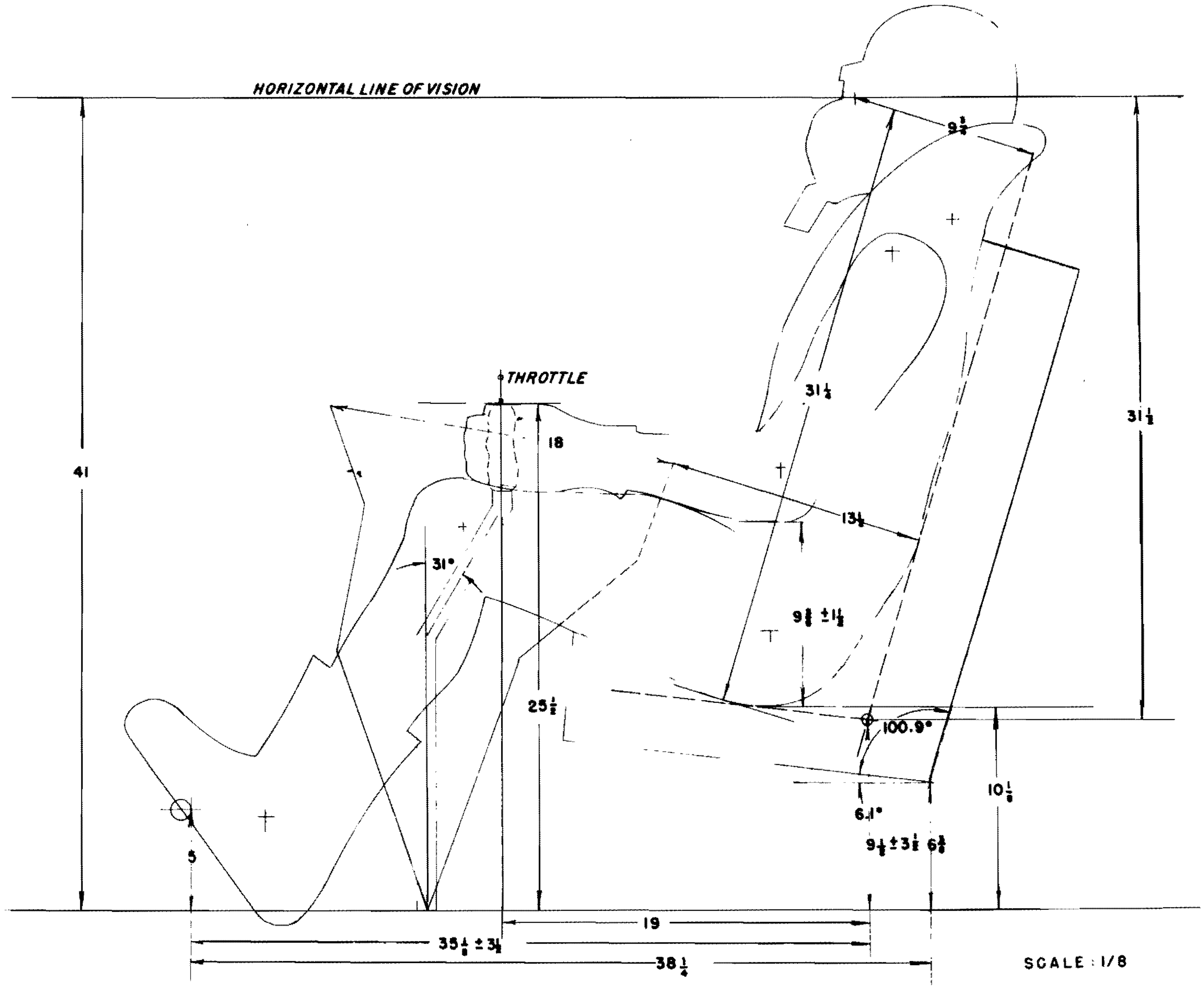


Figure 37 — Average Position of Seat in 41-in. Cockpit A.M.L. Test Seat

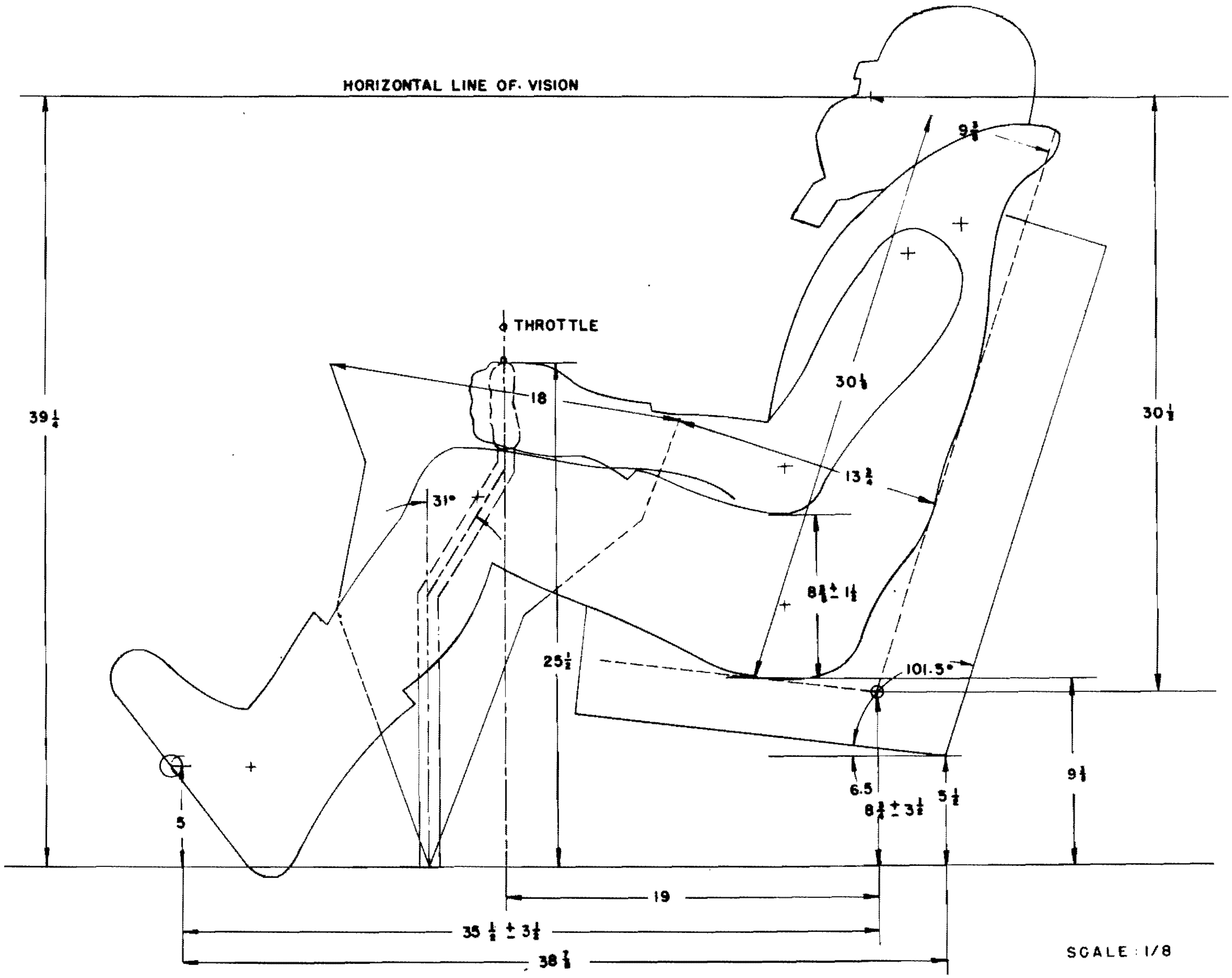


Figure 38 — Average Position of Seat in 39¼-in. Cockpit A.M.L. Test Seat

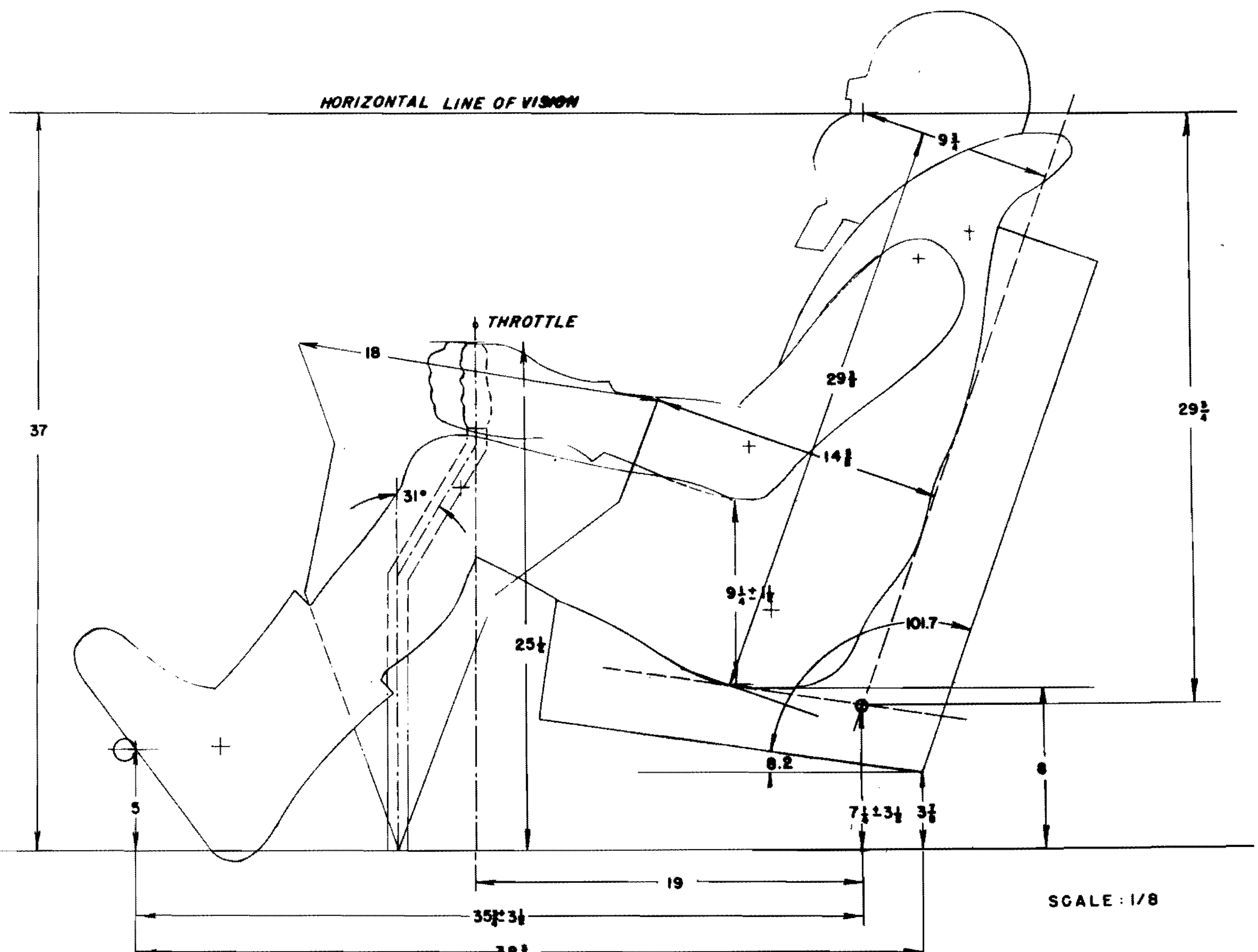


Figure 39 — Average Position of Seat in 37-in. Cockpit A.M.L. Test Seat

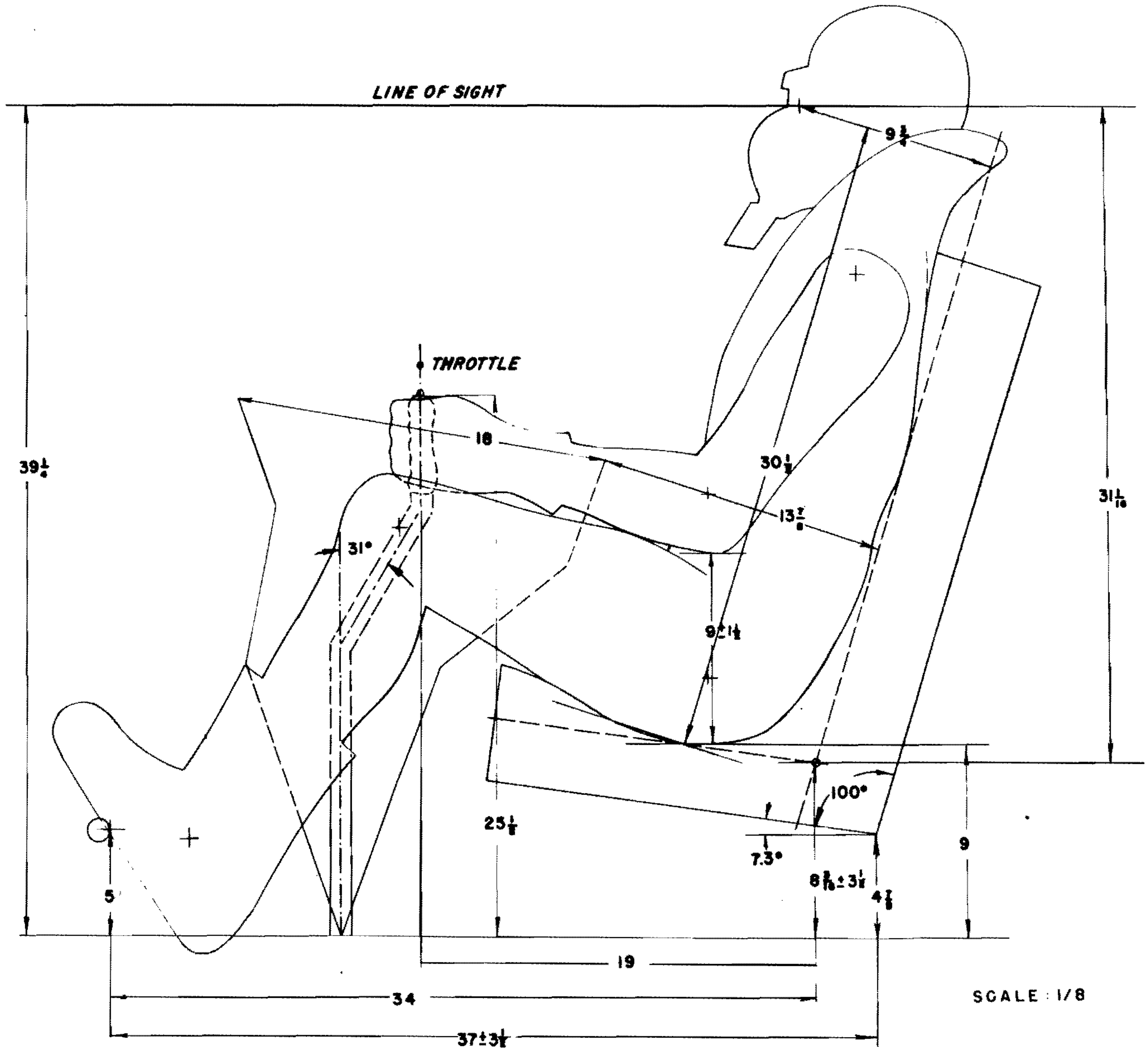


Figure 40 — Average Position of Seat in AAF Standard Fighter Cockpit A.M.L. Test Seat

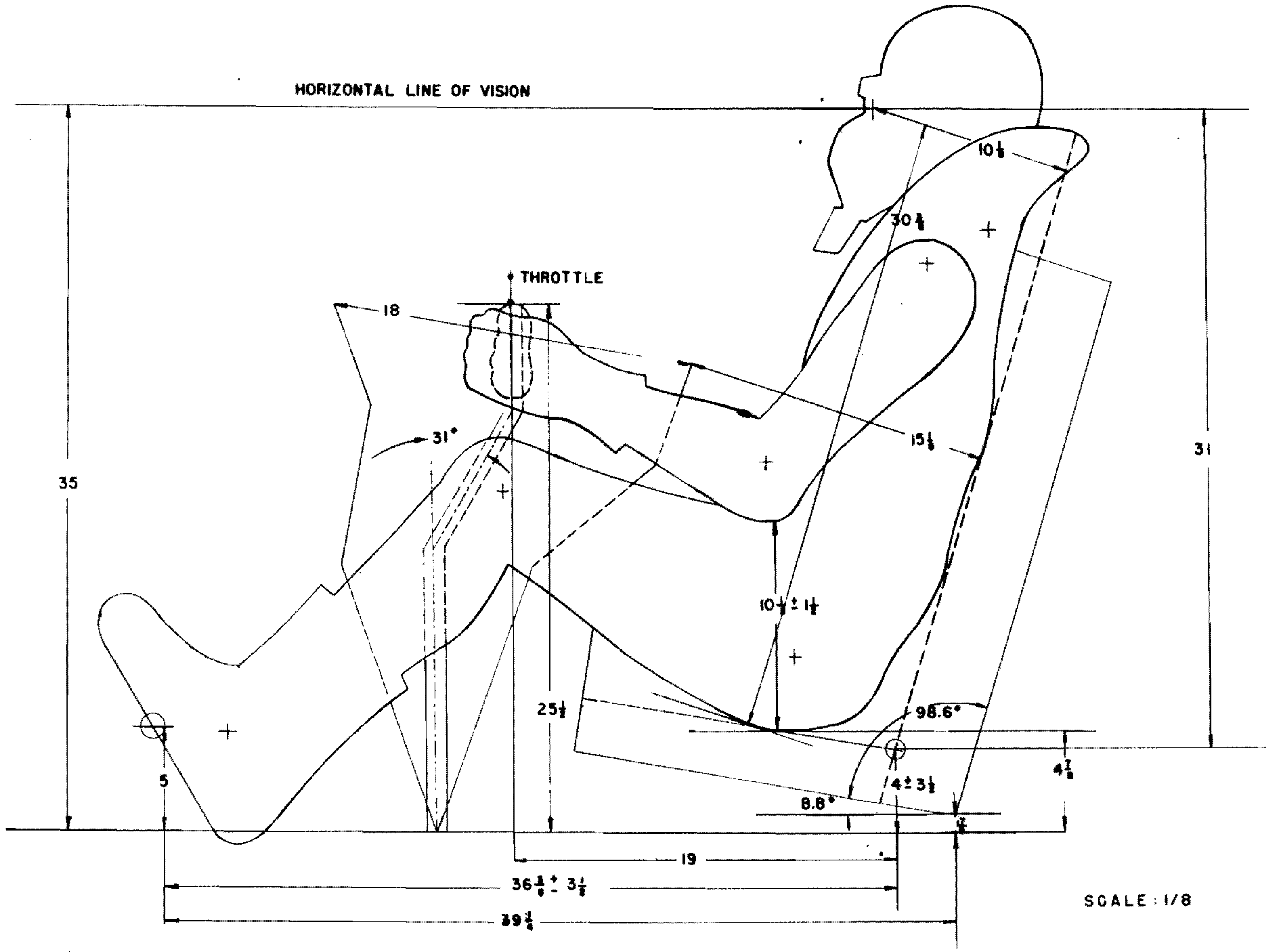


Figure 41 — Average Position of Seat in 35-in. Cockpit A.M.L. Test Seat

carefully to expose men to graded forces up to approximately 4.0 g for 0.05 to 0.3 sec in various postures. The stresses which man exerts under the above conditions on shoulder harnesses, seat belts, and other items of equipment will be considered. The goal of this progressive study will be a definite statement of requirements for the design and specification of devices to increase the tolerance of the flyer to linear decelerative forces.

5. *Ejection Cockpits.*

As a matter pertinent to safety and morale of aircrews, the flight surgeon always must consider methods of escape under all conditions. In the present project, studies are proposed to develop a system whereby, instead of bailing out in the conventional manner or using an ejection seat, the entire pilot's cockpit, while still pressurized, will be ejected. This system would answer the question of protection of the pilot from cold wind blast and anoxia at the moment of bailout at extreme altitudes. At safe altitudes, the cockpit shell, which has been stabilized during descent by a parachute, can be opened by an explosive device, and the pilot can continue his descent by conventional methods. The ejection seat is only a stop gap for installation in present high-speed aircraft as well as in training aircraft. To permit maximum crew survival in the future the ejection cockpit will be an absolute necessity, especially for aircraft with ceilings of 10 miles or more.

6. *Armor Protection.*

All crew compartments should have armor plate protection. Investigation carried out by personnel of the Aero Medical Laboratory with the help of Brigidier General Malcolm C. Grow showed that flak, which resulted in the death of a crew member, entered the aircraft from all directions. These investigations included careful autopsies to determine the type of wounds that resulted in death, and the results indicated changes in surgical procedure for those who return to the base wounded. The use of armor plate around the crew compartment seems just as logical as using bullet-proof gasoline tanks. Flak suits, originated by Brigidier General Grow, (so successfully used by the Army Air Forces and copies of which had been made just prior to the end of the war by the German and Japanese Air Force) would then be unnecessary.

7. *Atomic Energy.*

If atomic energy is used as a source of power for aircraft it will be a difficult problem from a weight standpoint to protect the crew from the neutrons and the gamma radiation. Extensive animal experimentation must be carried out on the effects of various types of radiation. However, the development of power from heat from an element made radioactive by placing it in a uranium pile would greatly simplify the problem as a comparatively small amount of material around the crew would protect them from the alpha rays. One only has to see and examine the Japanese patients made anemic and sterile by gamma radiation at Nagasaki or Hiroshima and read the autopsy reports on the patients who died from the effects of such radiation to appreciate the great difference between conventional and atomic bombing as far as the effects on humans are concerned.

RESEARCH IN AIR EVACUATION

The Army Air Forces have shown the tremendous military and medical value of air evacuation of combat casualties. Since large-scale air evacuation is a new departure, many problems in medical and operational procedure and equipment require investigation. A review of many of the problems of air evacuation is given in the Appendix.

TWO TYPES

There are two main types of air evacuation: the short flight from the combat zone to the combat theater hospitals, usually carried out by Troop Carrier Command and the long-range, transoceanic flight from the theater to the Zone of Interior, usually carried out by Air Transport Command. Because of the difference of times in flight, the methods of selection and care of patients are different in the two types.

Research on the short flight is concerned with temporary expedients such as allaying apprehension, preventing shock, administering oxygen or other emergency treatments when needed, and making the patient comfortable for a brief time. Most emergencies can be forestalled until expert medical care is available.

For the long-range evaucation flight, more attention must be paid to the patient's comfort, and often he must be on a litter for many hours. Feeding of patients while in flight, administration of oxygen, odors, sedation, restraint of the mentally disturbed, definitive or sometimes heroic emergency measures, resuscitation, excretory functions, vomiting, discharging wounds, hemorrhage and pain are a few of the problems which must be studied before treatments can be standardized.

TACTICAL ASPECTS

Research into tactical aspects has been neglected since air evacuation is a combined medical and operational procedure and cannot be developed by medical personnel alone. Instead of transportation of cargo being the primary function of all air-transport units, it is advisable to form an air-evacuation air-transport unit, the primary function of which is air evacuation and the transportation of medical supplies including whole blood and biologicals to forward areas, or to places where an emergency such as a flood, earthquake or epidemic occurs. Removable refrigeration facilities should be available in such aircraft. One such unit assigned to each tactical air force would guarantee a certain amount of air evacuation at all times, so that some confidence could be placed in plans of evacuation as coordinated with ground hospital units. A plan of coordination for evacuation by small plane from forward combat areas, with evacuation by large plane to rear hospitals, must be evolved.

EQUIPMENT AND AIRCRAFT

Research should be continued toward simplifying present equipment and toward meeting the demands for changes in design of transport aircraft. Equipment, techniques of loading and unloading, and operational procedures must be evolved for each new aircraft. In hot climates a portable cooling unit for use when the aircraft was on the ground would be of real value. Helicopters must be evaluated for rescue and evacuation from front lines (Fig. 42). A small plane of the L-5 type should be provided for carrying two patients instead of one and it also should have outlets for electrically heated casualty blankets. A small portable medical kit which unrolls and contains essential medical items is needed. Another small kit should be devised for carrying bed pans. For long-range flights, the distance between litters placed one above the other should be greater than at present to facilitate nursing care. However, the arrangement and construction of the litter straps should be so designed as to permit extra litters for use in emergencies. Flight nurses' clothing for both tropical and arctic climates should be improved. Equipment for feeding patients while in flight and that for warming and storage of food must be improved also. The war has shown that the equipment must be extremely simple and effective for nurses and technicians to use oxygen so that its maximal benefit may be conferred on the patient. A typical web strap type of litter installation demonstrates the stage to which this equipment has been developed so that more than 1,000,000 casualties could be evacuated successfully by the Army Air Forces (Fig. 43).

AIR EVACUATION UNITS

Experience of the war should be evaluated and new types of air-evacuation units tested. For example, there are too many nurses in proportion to the number of medical technicians in the present organization. It is not necessary for both a nurse and medical technician to attend every flight. Technicians alone can perform necessary medical duties on many flights. Medical supplies in sufficient quantities to allow the operation of a small dispensary should be provided for air-evacuation units which often are the only source of medical aid in an air-evacuation area.

EFFECTS OF ALTITUDE

Physiological responses to flight of normal human beings have been determined fairly well. Since these responses cannot always be applied to sick or injured patients, there remain for investigation, in part by a competent review of existing records, the effects of altitude on patients with anemia, lesions of the brain (injury, meningitis, brain tumor), abdominal disease (injury, intestinal obstruction, ileus), thoracic disease (pneumothorax, pneumonia, tuberculosis, penetrating wounds), and cardiovascular disease (coronary sclerosis, congestive heart failure). Immediately officers and technicians who had extensive personal experience on evacuation flights should be interviewed by a competent investigator. Some investigations can be performed safely on human patients in altitude chambers. By use of experimental animals much valuable information can be gained and clinical observation in actual air evacuation can provide the remainder of the desired information. This research can be performed by both military and civilian organizations. Arterial oxygen tensions, internal gas expansion, use of respirators, resuscitation and general therapeutic measures must be evaluated. The value of administration of oxygen during flight must be emphasized and aided by the development and use of liquid-oxygen equipment.

FLIGHT WITH TWO PATIENTS IN CAPSULES.
(PRACTICE)

Figure 42 — S-2800 XR-6 Litter Capsules

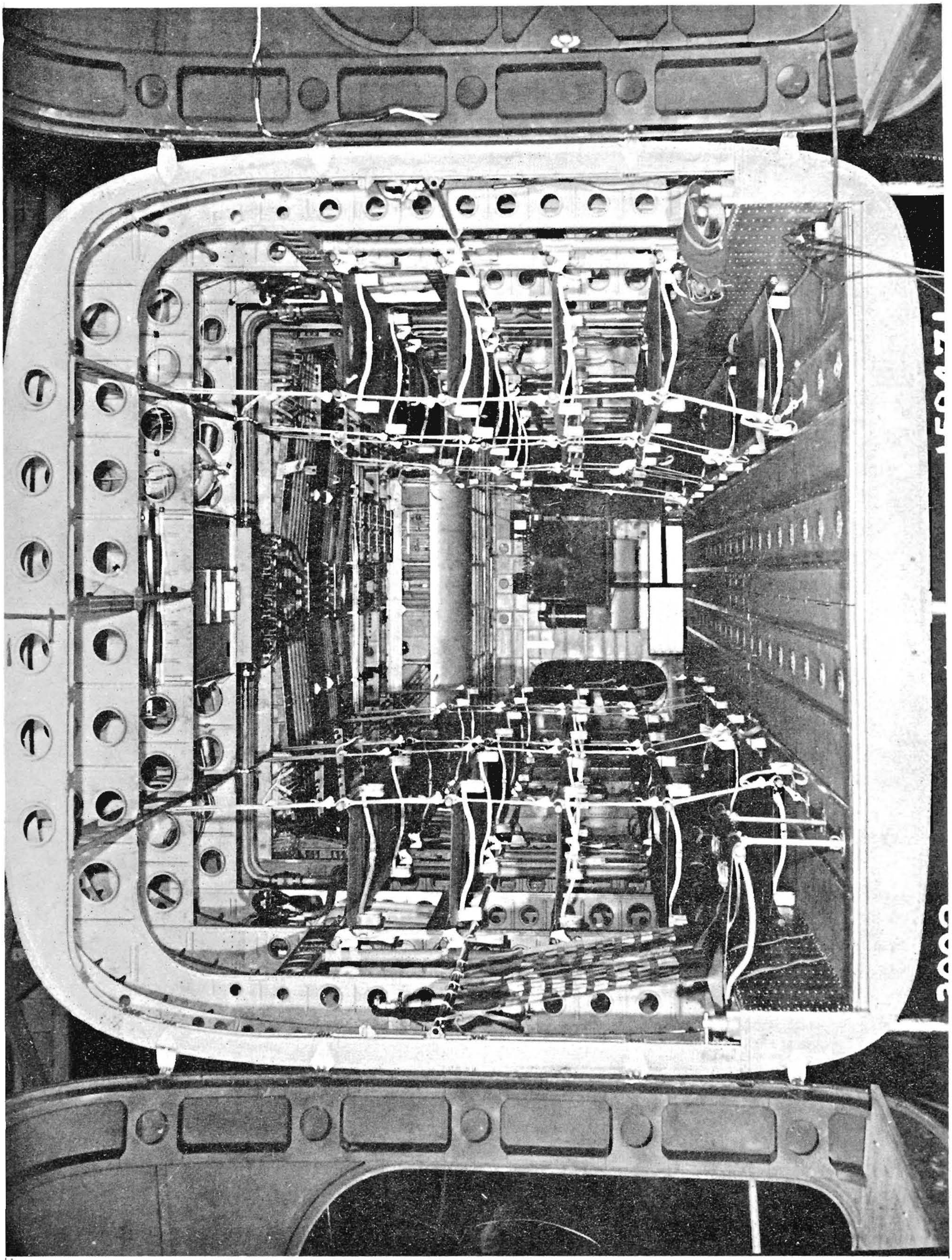


Figure 43 — Litter Installation in C-82

American, British and German experience has shown that, for extensive tactical air evacuation of casualties, where practical methods are used for selection of cases, the maximal safe altitude of flight is 3500 ft without efficient and sufficient oxygen equipment and even then certain cases ought to have available emergency oxygen equipment. For long-range flight in pressurized aircraft, the cabin pressure except for selected patients must be limited to correspond with this altitude. Extensive research, based on clinical observation of patients in pressurized cabin flights, must be carried out in order to establish methods of selection of cases and emergency measures in the event of explosive decompression and loss of cabin pressure.

A COMPARISON

In the early days of the war, Germans pioneered in large-scale air evacuation. Most of the experience gained has been available to the United States Army Air Forces for several years. In the later stages of the war, German progress lagged behind and, at this time, American advances surpass those of the Germans. There were less than five thousand patients evacuated by the Japanese Air Force from 1941 to 1945. Only one of the cargo aircraft had litter retaining equipment and that for just two patients.

PSYCHOLOGICAL RESEARCH

A point which cannot be overemphasized is that of integration of psychological research with design of equipment, selection of personnel and training of personnel. New equipment must be designed with a view to the individuals who are to be selected and trained to use it. As soon as designs have been accepted, moreover, plans must be initiated for improving the selection and training of personnel who are to use the equipment, so that by the time the equipment has become standard, procedures for selection and training also will be standard. Research on all of these problems should be coordinated with, and should be planned in cooperation with, Army Air Forces officers in each special field. Insofar as possible the test situation must approximate the flying situation and involve a total bodily response rather than a segmented response.

SELECTION OF AIRCREWS

The feasibility and value of selection of aircrew personnel, especially pilots, on the basis of a group of aptitude tests, has been demonstrated during the war. The Army Air Forces should undertake a continuous program of research on procedures for selection for military specialties, in order to accomplish the following objectives:

1. Replace selection tests currently used for pilots, bombardiers, navigators, gunners, radar operators and flight engineers with alternative groups of tests, and improve the predictive efficiency of the groups currently in use. The use of tests involving discrimination would be helpful.

2. Devise procedures for differentiating the occupational suitability of individuals for special tasks, such as pilot instructor, bomber pilot, fighter pilot, jet-plane pilot, operator of guided missiles, etc.

The German Air Force, prior to the war, made very extensive use of psychological tests for selection of officers and for selection of men for special types of training. However, their procedures were not well adapted to wartime requirements, when processing of large numbers of men is necessary. Their program and that of the Japanese Air Force lacked the progressive and changing point of view, which has characterized the Army Air Forces program. It is believed that only through continuous research can selection procedures keep pace with the changing job requirements which accompany the development of new weapons.

In order to secure maximal utilization of manpower, selection and classification must function as a continuous process. The selection of leaders, for example, should be based not only on test data but also on information accumulated during training and operations. The methods used in selection of potential leaders, however, should be developed through research. Selection of permanent officers for the Army Air Forces is another important research problem. At the operational level, the selection of potential lead crews and the selection of other key personnel is an important problem which has received attention from the aviation psychology program. Continuous research on these problems would make a contribution to the peacetime air force and would provide procedures in readiness for another emergency.

Most psychological research in the Army Air Forces has been devoted to the measurement of individual aptitudes and differences in ability, in order to select men who are especially well-suited for flying duties. It is equally important that studies be made to determine the capacities of individuals to operate new types of equipment. Research in this field should be concerned with such problems as: (1) determination of the ability to judge speed and distance from different types of airplanes and at very high speeds; (2) studies of human variability; (3) studies of reaction time in complex tests in high-performance aircraft; (4) studies of human capacity for learning to reach to the correct place for a control without confusing it with the controls located nearby; (5) effect of unfavorable operational conditions, such as high acceleration, extreme cold, extreme heat and humidity and high altitude on the speed and accuracy of performance; (6) studies of pilot error in aircraft accidents.

TRAINING PROCEDURES

Scientific research on training procedures has been relatively infrequent during the war as a consequence of the pressure for production of trained personnel. Psychologists are especially equipped to investigate problems in the field of human learning and have accumulated a vast literature of research on principles and techniques of efficient learning and training. Every specialized military occupation in the Army Air Forces for which individuals must be given special training should be made the subject of research on training procedures and training aids. Improvement in training procedures, and the accumulation of scientific data on principles of training for these specialities, is not only basic preparation for war emergency but also should lead to economical use of time, effort and money in peacetime training. Certain specific problems that invite scientific investigation may be cited as examples:

1. Very little has been done to evaluate the effectiveness of the Link Instrument Trainer and the value of various changes which have been proposed for, or incorporated in, that trainer. Development of the Dehmel trainer by the Curtiss-Wright Corporation has raised the basic question of whether a stationary ground instrument trainer is as effective as the Link type of trainer, in which the pilot moves about in two dimensions. Research on this and similar problems requires the development of quantitative indices of proficiency in actual instrument flight and the validation of trainer characteristics in terms of such measurements of proficiency. The same approach is applicable to the exact determination of the optimal training procedures and schedules to be used with ground trainers.

2. Many questions regarding procedures for training of pilots remain unanswered. For example, it is not known whether military pilots reach a higher level of proficiency in combat type aircraft when they begin their training on relatively slow and simple aircraft, or when they are given an equivalent number of hours in a type of training aircraft which closely simulates the combat aircraft, Again, the optimal number of hours of training on different types of aircraft or at different stages of training is not known. Psychological investigation of these problems and many similar problems would make use of the principles and techniques which psychologists have developed from study of human learning, transfer of learning to similar and dissimilar tasks, and forgetting.

Such studies as those outlined above should be applied to all occupational specialties of aircrew members to determine, on the basis of actual measurements of proficiency, the effect of ground training aids, air training procedures, rates of forgetting, frequency and duration of refresher training, etc.

EQUIPMENT DESIGN

Consideration of design of equipment should include not only efficiency of the equipment itself but also its adaptation to the human being who must use it, so that maximal efficiency in its control and operation may result. The German Air Force and the Royal Air Force both established research projects during the war to study psychological problems with relation to design of equipment. One important area of research concerns the design of instruments, radar screens, navigation tables and other displays so that interpretation of information derived from these instruments may be as accurate and as rapidly secured as possible. Two specific examples of this type of problem are the following:

1. Work already has been initiated by the Army Air Forces School of Aviation Medicine on evaluation of various types of flight indicators in terms of the efficiency with which they can be used during instrument flight. Basic problems on the ability to interpret symbolic instruments are involved. Is it better, from the point of view of the student pilot as well as from that of the experienced pilot, for the moving portion of the attitude indicator to represent the horizon or the airplane? Is it better for the indicator to represent the position of the plane or to indicate the necessary corrective movement to return the plane to straight and level flight? Different attitude indicators now in use represent different assumptions regarding the answers to these questions. The need is for quantitative measurement of pilot performance with different types of instruments under controlled experimental conditions.

2. Investigation already has been initiated at the Army Air Forces School of Aviation Medicine on the legibility of different types of marking and lettering on aircraft instruments. The research should be continued to the point where general principles regarding the legibility of instruments can be established as a guide to sound design of aircraft instruments, from the point of view of the pilot who must use them.

The human being who operates the machine controls it through the movement of some kind of control lever or wheel. Preliminary research in Germany and in England indicates that the efficiency of control varies to a large extent with different types of control mechanisms. It is important that the controls be adapted to the specific requirements of the task at hand and that such questions as the extent of control movement and the sensitivity, location and direction of movement, and other characteristics of the control, be studied in relation to the efficiency of operation that can be achieved by the operator.

PATHOLOGY

Investigation of all accidents by the flight surgeon determines more than the cause of death. The flight surgeon, by careful study can determine whether any specific structural part of the airplane was responsible for death, and the necessity for redesigning the aircraft from the standpoint of ditchings or emergency escapes.

TOLERANCE OF BODY FOR FORCES EXERTED ON IT

Recently acquired knowledge indicates that the human being, when placed in the right environment, has a much greater over-all tolerance of force than anyone believed possible. The g forces sustained, the influence of aircraft structure on producing injury and the type of injuries produced are being carefully analyzed by pathologists, both at the scene of the accident and at the necropsy table. Recommendations based on the data thus obtained are presented to the Office of Flying Safety and to the Flying Training Commands so that training procedures can be used to reduce the number of injuries resulting from existing equipment. The Engineering Division, Air Material Command, and aircraft designers should be kept informed so that biological and engineering aspects in aircraft design can be closely coordinated. Redesign of aircraft, according to principles based on pathological findings which define human tolerance to large forces, are strongly recommended. This project should continue as long as accidents which personnel could survive are important causes of disability and loss of life.

INJURIES WHEN AIRCRAFT IS OUT OF CONTROL

Studies have revealed that emergencies in which control of the aircraft is lost (low-altitude stalls, mid-air collisions, and so forth) make up only about 4% of the aircraft accidents, yet are responsible for 80% of the fatalities. Also shown is the notable lack of success in the use of the parachute under conditions characterized by high velocity, high radial force or brief time for escape. Results of these studies indicate the urgent need for aircraft designers to provide more successful means of aerial escape from aircraft that are out of control (examples: proper size for escape hatches; ejection seats). This problem exists for all types of aircraft. The project should be continuous inasmuch as each new type of aircraft and each new device for escape will present new problems.

The Germans had made no analysis of results of necropsy or of findings at the scene of crashes. Therefore, they failed to realize the statistical significance of inability to escape from aircraft which were not under control. They did develop the ejection seat but it was to be used only in extremely high-speed craft. They put great emphasis on improving parachute design and preventing parachute opening shock. American investigators until recently have devoted no time to the problem of ejection of the pilot.

CEREBRAL INJURY

Cerebral injury is the most common cause of death from aircraft accidents, yet only slight knowledge exists of the pathological physiology of brain injury. A new and easily controlled method of producing damage to the brains of experimental animals, by freezing, has been devised at the School of Aviation Medicine. A project coordinated with physiologists and surgeons to determine basic physiological factors and to improve methods of treatment should be undertaken. This project can be handled in a civilian institution and may require from two to five years. No work based on this experimental method has ever been undertaken in any country.

FROSTBITE

The pathological physiology of frostbite has not been fully determined. The type of frostbite which occurs in high-altitude flight is peculiar in that the exposure is often sudden and intense. Also, the chronic phase of frostbite has been the source of much loss of flying time. Basic knowledge of this problem must be obtained before effective treatment can be devised. Bailout by ejection seat at high altitude emphasizes this problem.

FATIGUE

The high incidence of combat fatigue in World War II demonstrates the need for study of the basic pathological changes which occur in this condition. This is an extremely difficult problem which already has been studied for years throughout the world. Recently, the Germans have placed emphasis on capillary efficiency, noting changes in the capillary sling (increased capacity, stagnation of blood, and higher permeability of the vascular wall). They have proposed selection of flyers based on their capillary efficiency and have suggested developing means of improving capillary efficiency.

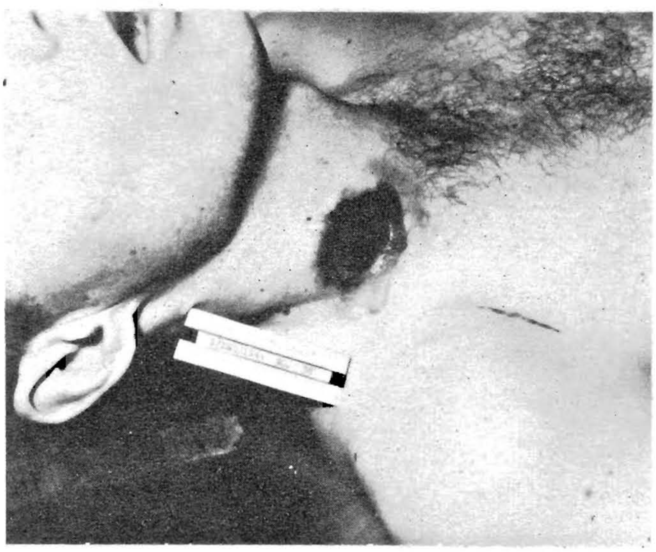
Practical methods for producing chronic fatigue in experimental animals have been devised at the Army Air Forces School of Aviation Medicine and experiments are proposed to make an exhaustive study of the histochemical changes in body tissues. This project will require several years and the technical ability of specialists in several fields of biological research. It can be carried out in a civilian institution.

INJURIES FROM FLAK

The success of the flak suit (Fig. 44), designed by the Army Air Forces for use by bombardment combat crews, is well known. Analysis of flying personnel wounded and killed by flak on missions over Europe demonstrated that a need existed for additional protection against flak at the neck and in the armpits. Therefore the earlier flak suit illustrated in Fig. 44 was improved and the type illustrated in Fig. 45 was developed. If the flak suit illustrated in Fig. 45 has been worn by the victim represented in Fig. 46, very likely his life would have been saved. Studies of the distribution of flak and the type of wounds inflicted on combat crews are important considerations. Also, each type of enemy ordnance equipment, whenever available, should be analyzed for the size of flak particles it produces (Fig. 47).

Figure 44 — AAF Helmet and Flak Suit

Figure 45 — Flak Suit . . . over Intermediate Flying Suit and Parachute



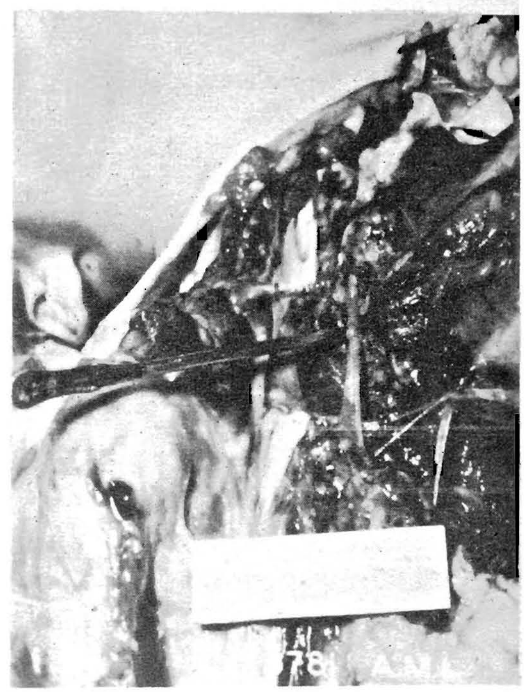


Figure 46 — Fatal Flak Wounds at Exposed Neck

Figure 47 — Fragments of a Single German 20 mm HE Explosive (60% Actual Size)

RESEARCH IN CLINICAL MEDICINE AND DENISTRY

The first investigation under the auspices of aviation medicine during World War I concerned selection and care of the flyer. Although aviation medicine has expanded to encompass consideration of personal equipment, oxygen equipment and factors in aircraft design, the clinical aspects of selection and care still retain their original importance. A new addition to aero medical research within the past few years has been aviation dentistry.

NEUROPSYCHIATRIC CONSIDERATIONS

Neuropsychiatric qualifications for flying jet-propelled or rocket-propelled high-speed aircraft probably will be the same as for flying present day craft, yet means of selecting men who are emotionally stable (who will not break down under the stress of handling fast, complex machines or under combat conditions) are becoming more important since flyers are being entrusted with more expensive aircraft than before and are being given greater responsibility.

No research to develop criteria for selection of personnel and for treatment and disposition of those who become neuropsychiatric casualties has been accomplished up to the present time, due to difficulties in coordination and due to the emergency of the war. This is a long-range problem and some beginning needs to be made toward its solution. Four years have now been lost to this valuable project.

Considering the great emphasis that Germans in the past have placed on psychiatry, and the fact that they pioneered the field, their developments have been surprisingly few. Their methods of treatment are considered out of date by Americans. Deluded by the belief that they were supermen, the Germans recognized no weaknesses in their pilots. The approach in treatment was that of stern suppression, so that the patient could not air his problems. Finding no other outlet, a great number of men with psychiatric problems committed suicide. Apparently the Germans tried to conceal their psychiatric casualties, saying in one breath that they had none and saying, in the next, that they could not get enough psychiatrists.

High-speed airplanes produce mechanical vibrations of all frequencies which affect the flyer. The Germans discovered supersonic vibrations in the Me-262 at speeds up to 950 km/hr, of magnitudes great enough to cause physiological injury. The jet bomb (V-1) was found to create a noise level of 180240 phons. Vibratory energy of this level produced loss of patellar reflexes and changes in the vegetative nervous system. If sympathetic nerves were cut along the leg vessels, the patellar reflexes were not lost. Injections of procaine could be used. Tests made at 3 or 4 m from the source of sound, with the ears protected by aluminum ear wardens, produced peculiar sensations (various parts "went to sleep"), difficult breathing, and double images resulting from vibrations of the head. No psychic damage was attributed to supersonic waves, since they do not register in consciousness.

A great deal of neurological research must be done to determine the role of vibrations in producing fatigue and the degenerative changes produced in the central nervous system by supersonic vibrations. Also, there is a field of research concerning the possible effects of drugs in preventing damage by supersonic vibrations This research calls for animal experimentation, electro encephalographic analysis and collaboration of the biophysicist, the pharmacologist and the pathologist. Some of the work can be carried out in a civilian institution, but aircraft for testing will be available only in the Army Air Forces.

USE OF DRUGS

Information contained in this section represents a continuous project which, with new advances in pharmacology and new achievements in aircraft, assumes great importance. Some problems of current interest, in addition to those already mentioned, are concerned with the following: vasoconstrictive agents to insure adequate airway to the nose, sinuses and ears for extremely rapid ascent or descent, or to restore grounded pilots to flying status; use of stimulants, such as benzedrine, to maintain flying efficiency for long periods; respiratory stimulants for casualties resulting from anoxia; use of analgesics, sedatives and narcotics by flight nurses and by crew members who must render first aid, and development of medication for prevention of motion sickness. Much of this research can be carried out in universities and industrial laboratories.

Members of the German Air Force made extensive studies of the effect of drugs on flying. They were particularly interested in a stimulant which would prolong flying efficiency and developed "pervitin," which was used with about the same success as that with which the Americans used benzedrine. The Japanese pilots were given benzedrine when fatigued and activated charcoal with a coating of sulfaguanadine to diminish gas. Supplmentary vitamins were also prescribed.

At the beginning of the war, it was thought that atabrine adversely affected perception of depth and many flying days were lost be removing men from flying status while they were taking atabrine. Later, it was proved that atabrine does not affect flying ability. Many drugs already have been evaluated for their effect on flying, but study must be continued to determine whether new drugs can be safely administered to flyers, passengers and patients evacuated by air.

INJURIES TO VARIOUS PARTS OF THE BODY

A study of victims of aircraft accidents conducted at the Army Air Forces School of Aviation Medicine has revealed that characteristic injuries occur in every system of the body. For example, the lungs are subject to hemorrhages and the ileum is the abdominal viscus which most commonly undergoes rupture. By continuation of this study, the clinician will be provided with valuable information on what he may ex- in an injured patient, thus enhancing his ability in diagnosis, prognosis and treatment.

It is now generally recognized that fractures alone do not cause death. The need for surgeons and pathologists to study concussion and shock produced by instantaneously acting large forces is clear. Follow-up studies of personnel involved in accidents, whether apparently injured or not, is a matter of concern. Neuropsychiatric and orthopedic disabilities resulting from accidents should be evaluated on a long-term basis. Although initiated by pathologists, this study should be carried out in its final phases by clinicians. Although this broad problem has been studied by physicians the world over, the Germans contributed nothing significant to it during the war.

FIRST AID

Experience in the war showed that during long-range flight the occasions were numerous on which a flyer was called to administer first aid to a fellow crew member. The advent of dried-blood plasma, pneumatic resuscitation from the oxygen system of the plane, and electrically-heated casualty blankets, calls for specialized training of aircrew members. Studies to determine the types of injuries encountered with changes in aircraft design, to develop appropriate equipment, and to standardize new training and first aid procedures should be carried out in peacetime.

RESPIRATORY AND RELATED CONDITIONS

Numerous factors peculiar to the training and activities of an air force increase the spread of respiratory disease at rates exceeding those found in Army Service Forces and Army Ground Forces installations. A comprehensive study made by Dr. Colin MacLeod for the Committee on Medical Research disclosed these facts and attributed them, in part, to the necessary crowding of students in classrooms in the Technical Training Command. Another factor to be considered is the confinement of aircrews for long periods on flights in long-range bombers. Other factors to be considered are aerosinusitis, aero-otitis and persistent infection of lymphoid pharyngeal tissue. Increased velocity and operational altitude of future airplanes will exaggerate the importance of these diseases. In addition, many minor infections, such as otitis externa, cause grounding of aircrew personnel, but may permit treatment of ground personnel on duty status. Accordingly, the Army Air Forces should undertake a long-range program aimed toward reduction of respiratory disease.

Such studies must, of course, include all factors, such as epidemiologic aspects. These embrace thorough bacteriological surveys of military populations and development of methods for decrease of bacterial contents of classrooms and barracks. In addition, adequate methods of treatment must be sought. These methods should include application of such new chemotherapeutic and antibioltic agents as may appear from time to time.

Increasingly high rates of ascent and descent, such as occur with vertical rocket take-off or free fall parachute descent, call for study of the adaptability of the ears and sinuses, discovery of measures to prevent barotrauma and development of training procedures for flyers which will help them to adapt to rapid changes of altitude.

Malposition of the lower jaw frequently disturbs function of the temporcomandibular joint. A commonly associated finding is stenosis of the eustachian tube and aero-otitis. The functional pathology of this condition has not been solved but certain studies (such as those of Dr. John R. Thompson of the University of Illinois) indicate that the solution may be forthcoming with the aid of the Breadbent-Bolton cephalometer. This is an instrument used to position an individual in relation to certain landmarks on the skull and face in such a manner that a nearly exact reproduction of the position can be obtained at later dates. By this means the growth and development of the face has been recorded over periods as long as 15 years. This research must be a joint effort of otologists and dentists.

The effect of radiation therapy (roentgen rays and radium) applied in connection with obstructive lymphoid tissue in the nasopharynx will require years of study before appraisal can be forthcoming. It is urged that the facilities of the research section be turned to fundamental and basic investigations in physiology and pathology of function of the eustachian tube and that such studies be made in close collaboration with civilian institutions. In this field, investigators in the United States are more progressive than the Germans, who have not recognized aero-otitis as a serious problem.

PHYSICAL AND PSYCHOLOGICAL FITNESS

A continuous project of the School of Aviation Medicine, underway since the organization of the Air Corps, is the determination of physical and psychological requirements for flying. This is, possibly, the most important work of the Army Air Forces medical services. Certain new types of aircraft may call for special physical powers such as unusually high cardiovascular and respiratory fitness. A reliable test of these functions, for frequent use on large groups, should be developed.

The Army Air Forces method of selecting and maintaining flyers of high qualifications has been the most successful in the world. As the war progressed, our flyers became better, while those of the German Air Force deteriorated.

In spite of its success, a critical appraisal of the evolution of the "64" physical examination for flying, reveals much room for improvement. A likely reason for our success was not perfection of the examination but an adequate source of pilot trainees which made it possible to maintain physical requirements at a high level. Standards for qualification were established rather arbitrarily during World War I, and exist today, with only minor modifications, for the selection of personnel. Due to the urgency of the war, validation of physical requirements has received only preliminary attention. Exclusive test-retest values of various methods of examinations are indicated. On the other hand, the psychological program for selection has been carefully validated and is a highly efficient procedure. Minimal requirements for several physical functions probably could be lowered for the whole program, or for certain categories of flying personnel, thus eliminating some waste of available manpower in case of emergency.

Continued research calls for the coordinated efforts of all branches of clinical and research medicine and psychology. The most important criteria for selection of flying personnel are based on the following functions: vision, hearing, neuropsychiatric normality, cardiorespiratory efficiency, physical prowess, and psychological adaptability.

Some factors will appear from time to time and will require that physical standards always be amenable to change. Some of them have been mentioned in another connection. They are as follows: new advances in aircraft, equipment and drugs, which call for new or different qualifications in pilots and crew members; availability of pilot material in relation to the number of flyers needed (example: in peacetime the number of pilots will be small and the physical requirements can be strict); research into aviation physiology and psychology which continues to reveal new information about the flyer and to clarify physical requirements; validation studies, once underway, which point the way to revisions in physical requirements, and the development of new techniques or instruments for performing both physical and psychological examinations.

In connection with the ophthalmological portion of the examination, experimental work on the selection of techniques of examination must be continued, this to be followed by prolonged validation studies. Certain questions are yet to be answered if the Army Air Forces is to derive maximal benefit from flying personnel. The most important is: What visual efficiency is needed for a man to fly?

Extremely rapid ascents and descents of newer aircraft and the development of new drugs and of new communications equipment will influence physical requirements for the ear, nose and throat examination. Validation will be pushed a step forward by the development of group testing by audiometer and by other tests.

For the general medical portion of the examination, data already on hand should add a great deal of information as to the actual value of physical standards of flying. A concerted effort should be made to integrate all the requirements so that each will be given its proper weight in the physical evaluation of a flyer. Along those same lines, a program should be set up to determine the long-term effect of flying on the general health of the individual. It is believed that this will show that flying has no effect on health but, as yet, no long-range program has been instituted to determine this. The Army Air Forces offers opportunity for carrying out such investigative work.

For the psychological portion of the requirements, see the section on Psychological Research.

Physical requirements for flying in the German Air Force were similar to those of the Army Air Forces with the exception that the Germans were more liberal and gave the medical examiner more leeway in accepting or rejecting the candidate. No program of validation had been carried out and German Air Force requirements were purely empirical.

CARE OF THE FLYER

The experience of medical officers in tactical units during World War II has resulted in acquirement of much information about care of flyers. Many earlier conceptions of what makes for flying efficiency were found to be erroneous. The geographic location of an air force and the operational situation were found to be important factors in determining the proper care of the flyer.

The ever-changing situation calls for continuous analysis of the medical problems of the flyer in actual operation. The field is one for combined research and clinical practice.

First, an important field of research is continuous statistical analysis of all causes of loss of flying time in the various theaters. This project was underway during the war and did much to focus attention on medical problems which, although not peculiar to the Army Air Forces, are more serious when they involve flyers. As an example, it already has been mentioned that respiratory infection keeps a flyer out of the air while a ground soldier may be treated on duty status. Since certain diseases temporarily render airmen unable to fly, and thereby reduce their combat efficiency to a minimum, whereas these same diseases tend merely to impair the operational efficiency of ground forces personnel, it is necessary that the Army Air Forces carry out independent research and develop more effective measures for control of disease than are used by the Army Service Forces or the Army Ground Forces.

Second, specific problems and their relation to the high-speed, high-altitude flying that is expected of newly developed aircraft must be encountered in dealing with flyers under actual service conditions, so that proper corrective measures can be instituted.

Third, attention must be directed toward minimizing fatigue, anxiety and the incident of psychoneurosis among flyers. It is believed that investigation of this matter would indicate the necessity of establishing time limits for combat tours and a definite rotation policy. Such a study should provide definite information for flight surgeons who are called on to make disposition of flyers. Recommendations should be based on thorough understanding of the criteria for diagnosing fatigue, of the stresses which a flyer will tolerate and of the rest required to prevent or cure fatigue.

Fourth, a study in the field of preventive medicine should be made. The Eighth Air Force program of using sulfadiazine for prophylaxis of respiratory infections during the winter of 1944-45 materially increased the number of flyers available for combat during the period. Malaria, diarrhea and venereal disease have taken tremendous toll of combat strength during the war. The Ploesti raid was almost called off because of an epidemic of diarrhea among the flyers. We cannot afford such a risk in the event of another war.

The dentist must collaborate with the ear, nose and throat specialist, since, as has been said, malposition of the lower jaw long has been considered to be one cause of aero-otitis. The dentist must also maintain close relationship with the surgeon and pathologist in studies of maxillofacial injuries, the most common nonfatal type of injury resulting from aircraft accidents. The nature of the injury, the mechanism of its causation, the therapy employed and the results of treatment deserve more critical analysis than they have had. In addition to lowering morbidity and mortality among victims of facial injuries, evaluation of such data undoubtedly would influence the design of safety devices in the cockpit, on the instrument board, and on the shoulder harness. Investigation of this problem would be materially aided by use of the Broadbent-Bolton cephalometer. Some German Air Force hospitals included facilities for treatment of maxillofacial injuries and dental disease, staffed either by a dental officer or a medical officer.

Pilots in flight, particularly under hazardous conditions, develop emotional strain and apprehension to such a degree that in many instances injurious habits are developed which cause, or maintain, periodontal injury. Sucking habits, tongue habits and clenching of the teeth are examples. This fact, pointed out by Major A. A. Goldhush, DC, requires further investigation.

More study is required to determine the causes of toothache from decompression coincident with altitudes above 5,000 or 8,000 ft. The incidence of this affliction among flying personnel has been reported to be from 1.2 to 5.8%. The final determination of methods of prevention will be directly related to improved operative techniques which should be developed in an effort to reduce thermal and traumatic injury of the dental pulp. Aerodentalgia in upper posterior teeth has been shown by Captain R. H. Kennon, DC, to have a direct relationship to maxillary aerosinusitis. He found the incidence of maxillary aerosinusitis in 330 cases of toothache to be about 10%. Causative factors for aerodentolgia will continue to arise as speeds and altitudes are increased. Little is known, for instance, of the effects of vibration and cold on the oral structures.

The development of mobile dental units should be continued by the Army Air Forces as they have proven their worth in the field. (Fig. 48).

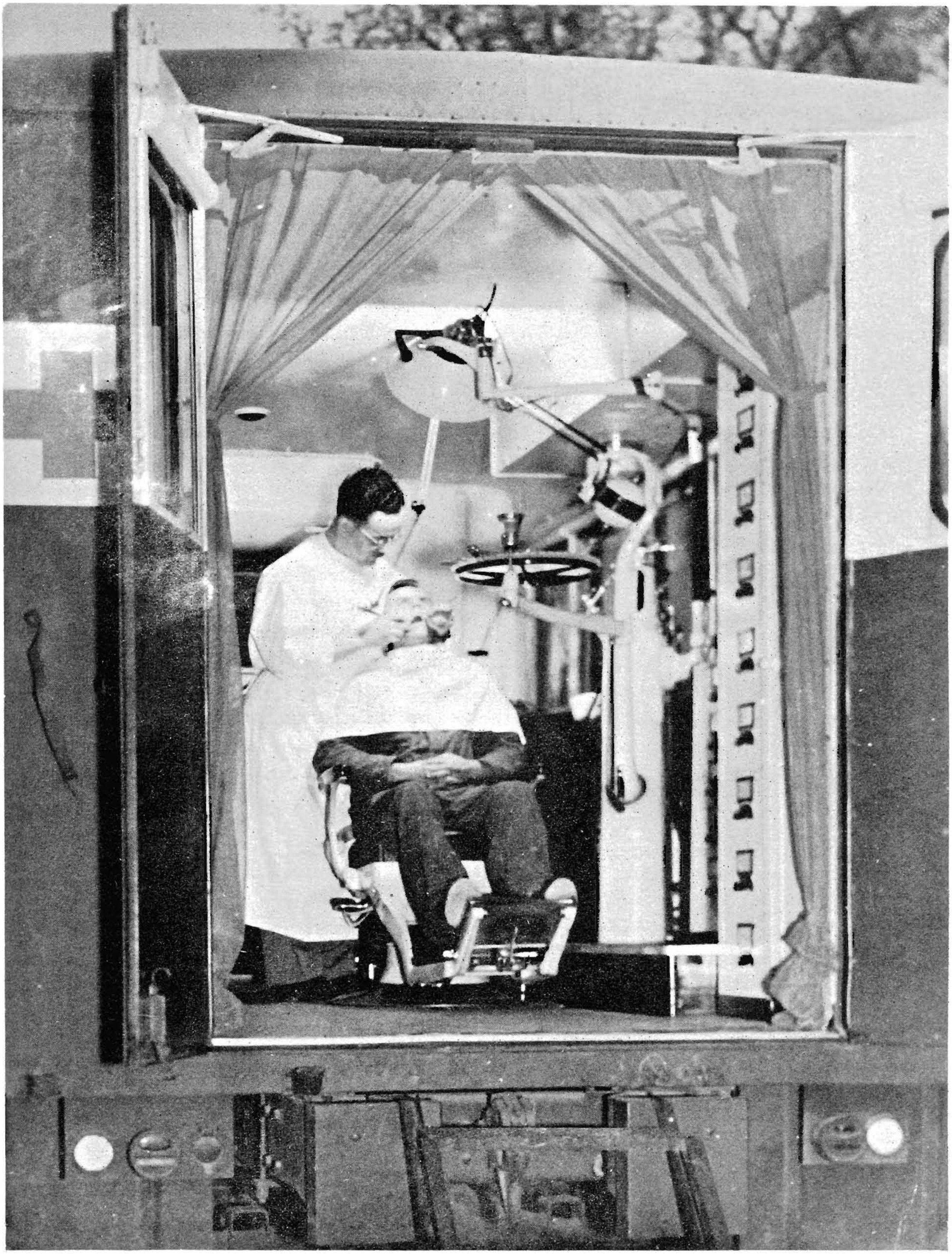


Figure 48 — Portable Dental Dispensary

AERO MEDICAL RESEARCH FACILITIES AND PERSONNEL

The province of aviation medicine extends from initial selection of personnel for pilot training to consideration of human factors in the design of aircraft and equipment. Solution of the many problems within this wide range demands the attention of many specialists and the use of much equipment, and whereas much of the research must be conducted in close association with pilots, aircraft and service conditions within the Army Air Forces, delegation of certain problems to civilian agencies and their specialized personnel and equipment is often advisable.

The existence of a diversified program carried on at agencies distributed throughout the country calls for a single central directing agency (The Air Surgeon's Office) with authority to determine whether any prospective medical problem falls within the realm of aviation medicine. Central direction should tend to encourage and stimulate research and not impair it by administrative restriction or premature condemnation. Most suggestions for research will come from the field and from specialists in the various research agencies, not from the central director. Considerable latitude should be allowed research agencies in their selection of research methods. Rules governing the activities of The School of Aviation Medicine and the Aero Medical Laboratory should not be inflexible. Facilities of personnel and equipment make it practical for some basic research to be carried on at the Aero Medical Laboratory and some testing of equipment to be done at The School of Aviation Medicine. Occasional duplication of effort should not be restricted, especially in basic research categories. If a research project is worthwhile, it is usually worthy of the attention of more than one investigator at more than one place.

A great responsibility of The Air Surgeon, or central director, is coordination of Army Air Forces medical research with the many interdependent problems of aviation medicine and administration. He effects this coordination by systematic orientation of laboratory directors in the over-all research program and by well-organized liaison among Army Air Forces medical research facilities and other military and civilian agencies. Placement of personnel has been, and should continue to be, vested in the Air Surgeon.

FACILITIES IN THE ARMY AIR FORCES

Present facilities for research have evolved from small, prewar organizations to two large, well-equipped service laboratories, a field testing organization and several associated civilian aero medical laboratories. These organizations will carry on the bulk of postwar research. The Aero Medical Laboratory at Wright Field and the Army Air Forces School of Aviation Medicine are the two principal research laboratories in the Army Air Forces.

THE AERO MEDICAL LABORATORY

This laboratory is part of the Engineering Division, Air Materiel Command and maintains close technical liaison with the Air Surgeon. Its duties are to carry on the following activities:

1. Conduct research to determine the effect of flight on the human organism and recommend methods for maintaining and improving the efficiency, health and safety of flying personnel.

2. Conduct research on the physiology of respiration under reduced barometric pressure (high-altitude flight) and determine the basic oxygen requirements for all flight conditions.

3. Develop, standardize and test all items of oxygen equipment used in connection with military flying.

4. Develop, standardize and test all items of oxygen, carbon dioxide, and acetylene generating equipment.

5. Conduct research on effect of acceleration and decleration on flying personnel and determine limits of human tolerance to these forces.

6. Develop, standardize, and test all items of anti-g protective equipment.

7. Develop shatterproof airborne and ground pressure vessels for storage of gases under pressure.

8. Develop inflation valves and cylinder units for emergency sea rescue equipment.

9. Develop, standardize and test items of medical and dental equipment used in connection with military flying.

10. Conduct research on human tolerance to cold, heat and humidity and determine human requirements for heating and ventilation of aircraft.

11. Conduct research on the effect of explosive decompression on flying personnel and determine safety requirements, with relation to aircrews, of pressure cabin aircraft.

12. Study methods of improving visual efficiency in military aircraft.

13. Develop, standardize and test all items of eye-protective equipment used in connection with military flying.

14. Conduct research in anthropometry of flying personnel and advise other laboratories on problems related to size, spacing and arrangement of equipment and aircraft compartments that affect efficiency of flying personnel.

15. Publish a monthly journal, "The Air Surgeon's Bulletin," devoted to articles of aero medical interest.

16. Test, appraise and recommend for standardization various items of personal protective equipment for ground safety.

17. Maintain liaison with the Office of The Air Surgeon on matters pertaining to aviation medicine.

18. Conduct research, develop instructional methods and disseminate information on hydroponics, as they affect all personnel of the Army Air Forces, maintain-

ing close liaison on these matters with the Air Quartermaster General, and man and operate field stations in hydroponics.

19. Conduct psychological research to determine the capacities of individuals to operate new types of equipment, as an aid in the design of such equipment, to the end that the final product will be best adapted to the man who must use it.

20. Prepare instructions for operating, servicing and overhauling equipment and accessories designed by the Army Air Forces for which a need has been determined, and transmit manuscript copy of such instructions to Maintenance Data Section for publication.

The principal research equipment of the Aero Medical Laboratory includes the following:

1 Twenty-man low pressure chamber.

1 Sixteen-man refrigerated low pressure chamber (down to − 80°F).

1 Automatic stratosphere test chamber for personnel and equipment (simulates flight pattern with respect to altitude and temperature; + 150°F to − 100°F).

2 Two-man low pressure chambers.

1 Human centrifuge with electronic controls and devices for recording blood pressure, blood flow, vision, respiration, pulse rate and acceleration (operation up to 20 g).

1 Human decelerator (under construction).

1 Human vertical accelerator.

1 All-weather room (temperature range: − 50°F to + 165° F).

1 Adjustable and recording test seat for studies of seat comfort.

2 "Breathing heads" (mask, helmet and goggle testing apparatus) with electronic control and devices for recording breathing pattern, surface temperature and temperature of expired air and humidity.

2 Instrument stratosphere chambers (down to − 100°F).

1 Hot box for heat duration tests of equipment (up to + 500°F with humidity controls).

Nutrition kitchen.

Instrument wind tunnel (from 20 ft/min to 10 mph).

Cockpit mock-ups for explosive decompression, visual and ventilation studies and tests of cabin pressure regulators.

2 Thermal men (copper) with surface-temperature control and recording equipment.

X-ray equipment for routine diagnostic studies.

Medical library (3000 volumes).

Machine and carpentry shop.

Photography, reproduction and art unit.

Editorial and art facilities and equipment for publication of the "Air Surgeon's Bulletin."

Quarters for experimental animals.

Pathology laboratory for section and staining of tissue.

Aircraft oxygen test and development equipment includes the following additional items:

Electronic pressure flow and nitrogen determination equipment.

2 Vibration stands for testing instruments.

Oxygen-regulator test stands for testing pressure, flow rates and dilution characteristics.

Oxygen blinker life test stands.

1 Desiccant test stand.

1 Cylinder valve tester.

Liquid oxygen, moisture and anlyzer and gages.

1 Spontaneous combustion bomb.

Miscellaneous mechanical testing equipment for instruments (flow-meters, pressure gages, pressure recorders).

Miscellaneous electronic testing equipment for instruments (voltmeters, ammeters, potentiometers, galvanometers, temperature records).

Hydrostatic test equipment for cylinder and tubing.

Equipment for analyzing purity of oxygen.

Equipment for testing inflation gear of life rafts.

For phsyiological and biophysical research the following additional items are included:

Electrocardiograph, automatic pulse recorders, ballistocardiograph and tilt table for studying subject being subjected to acceleration.

Impact force recorders (tensiometers), anthropomorphic dummies and recording devices for studies in parachute shock forces and rates of descent.

Bacteriologic equipment for studying tropical deterioration and fungicidal agents.

Equipment for studies of respiratory physiology, toxic gases in aircraft and fatigue (photospectrometer, photoelectric colorimeters, Millikan colorimeter, Van Slyke and Haldane analysis apparatus, quartz spectrometer, spirometers, Abbe refractometer, optical flowmeter, electronic oxygen analyzer and ergometers).

Sound analysis equipment.

Visual study equipment (dark room, 96 in. electrically controlled perimeter, Beckman quarts spectrophotometer, dark adaptometers, gyrotheodolite).

Anthropemetric study equipment including universal test seat, measuring devices and model making equipment.

Thermal testing and research equipment for the study of clothing and other thermal protective devices.

In addition, all types of aircraft are available from Flight Section for actual flight tests.

THE SCHOOL OF AVIATION MEDICINE

This organization is independent of the remainder of Randolph Field. It has its own commandant and is divided into the school proper, the hospital and the research laboratory.

The duties of the school are as follows:

1. To offer the following courses:

Aviation medicine — to medical officers.

Flight surgeon's assistant — to medical department enlisted men.

Flight nurse — to nurses.

Medical air evacuation technician — to medical department enlisted men.

Refresher course — to medical officers.

The duties of the hospital are to care for all routine medical work of Randolph Field and provide clinical material for teaching and research.

The duties of the research laboratory are to carry on the activities listed below:

1. Determine the ophthalmologic requirements of the physical examination for flying.

2. Conduct research on visual acuity, extra-ocular muscle balance, night vision, color visual acuity, and depth perception to determine basic physiological facts. Conduct suitable tests for determining these functions in flyers, and determine the proficiency of function required of flyers.

3. Study patients with opthalmologic abnormalities, with a view to improving methods of diagnosis and treatment.

4. Study the effect of barotrauma on the cavities of the head, including the basic physiological and pathological facts with relation to the eustachian tube, the middle ear and accessory nasal sinuses. Study particularly the effect of lymphoid tissue, in the upper respiratory passages, on ventilation of the cavities of the head and the use of radiation therapy in treatment of lymphoid obstruction.

5. Conduct research on the quantitative evaluation of hearing and the influence of noise, infection and other factors on loss of hearing; develop criteria and equipment for group audiometric testing.

6. Study diseases of the ear, nose and throat to improve means of diagnosis and treatment.

7. Study vestibular function to determine its role in motion sickness, acute disorientation and blind flying.

8. Determine the requirements relative to the ear, nose and throat in selection of flyers.

9. Carry on clinical and experimental studies of frostbite of flyers, to determine the pathological and physiological facts concerned with the objective of improving treatment.

10. Determine the type and frequency of occurrence of peripheral vascular disease in Army Air Forces personnel and the effect of high altitude on patients with various types of vascular diseases.

11. Make clinical studies of the effect of blood fractions on wound healing following operations performed for pilonidal cysts and sinuses and conduct basic research on the fate of blood fractions implanted in tissue and their effect on healing of wounds.

12. Make experimental studies on the effect of intra-arterial transfusion upon irreversible shock.

13. Make experimental studies of the effect of various chemotherapeutic agents on growth of tissue and repair of wounds.

14. Study various surgical techniques for repair of common remedial defects, such as hernia, pilonidal sinuses, varicocele, hemorrhoids and varicose veins.

15. Study agents for treatment of rickettsial diseases, including clinical and experimental trials and pharmacologic analysis of drugs.

16. Make pharmacologic and therapeutic trials of drugs received from the Board of Coordination of Malarial Studies.

17. Carry on studies in the field of tropical medicine which are of particular importance to Army Air Forces flyers from the standpoint of reducing loss of flying time.

18. Make operational, clinical and experimental studies on the cause and treatment of motion sickness and on tests for susceptibility.

19. Study the effect of crash injuries on experimental animals.

20. Make clinical studies of liver function by cephalin cholesterol flocculation in the presence of infectious diseases not attended by damage to the liver.

21. Make clinical studies of maximal ventilation capacity on patients with respiratory disease.

22. Carry forward studies of chemotherapy with relation to control of respiratory infection among Army Air Forces personnel and bacteriologic and pharmacologic studies of sulfonamides, penicillin, streptomycin and other antibiotics; these studies to be prosecuted in conjunction with the medical services of Army Air Forces hospitals in the continental United States.

23. Study resistance to drugs of streptococci obtained in cultures derived from patients in the continental United States, with the view of selecting or developing chemotherapeutic agents that can be effectively used both in prophylaxis and treatment of infections with these streptococci.

24. Study Army Air Forces personnel returned from overseas for detection of carriers of enteric diseases and investigate new drugs for treatment of these diseases;

maintain a diarrheal disease control laboratory to ascertain the causes of diarrheal outbreaks in the continental Army Air Forces.

25. Foster studies by bacteriologists and otologists on the cause and treatment of otitis externa, which has caused much loss of flying time.

26. Develop and validate psychologic methods for selection of aircrew members, with special reference to each crewman's position, including pilots, navigators, bombardiers, gunners and radar operators.

27. Develop and validate psychological methods for selection of special ground crew personnel, such as ground radar operators.

28. Develop psychomotor testing equipment for use in selection of aircrew members, special ground personnel and prospective pilot trainees from among the cadets of the United States Military Academy.

29. Make psychological evaluation of flight indicators; study legibility of aircraft instruments and arrangement and identification of aircraft controls.

30. Make psychological evaluation of trainees in instrument flying; coordinated with this, study eye movements during instrument flight and develop a method for measuring path of flight during flight by instruments.

31. Make basic studies of respiration and cardiac function on human and experimental subjects for application in aircraft operations; study design of equipment, treatment of respiratory diseases and selection of personnel.

32. Study the pathological physiology of asphyxia resulting from altitude anoxia, with the object of developing preventive and therapeutic measures.

33. Study the pathological physiology of abdominal gas pain resulting from flight to altitude in order to determine the cause of the pain and to develop a staisfactory treatment.

34. Prosecute research into tests of physical fitness for aircrews, ground crews and convalescents.

35. Develop methods of physical training for aircrews, ground crews, convalescents, neuropsychiatric patients and patients with rheumatic fever; evaluate effects of various physical training programs on the physical fitness of Army Air Forces personnel; study the influence of voluntary selection of activities on physical fitness.

36. Make kinesiologic studies of various exercises to determine their value as incorporated in physical training programs or physical fitness tests; evaluate the strength of extremities and muscle groups in relation to size and weight of flyers in order to provide knowledge to aircraft designers concerning forces necessary to operate controls.

37. Study neuropsychiatric qualifications required for flying with a view to improving selection methods, and improving methods of diagnosis and treatment of combat fatigue and anxiety reactions.

38. Make neuropsychiatric evaluation of flyers to determine the results of combat experience, to improve methods of selection and to serve as a validation study of present neuropsychiatric methods of selection.

39. Distribute medical literature as designated by the Air Surgeon, to military and civilian agencies interested in aviation medicine.

40. Edit and publish the "Flight Surgeon's Reference File," a loose leaf book which is periodically revised and distributed to Army Air Forces hospitals, to aviation physiologists and to flight surgeons for dissemination of aero medical and administrative information.

41. Maintain a library and medical intelligence file of all current, relevant, important medical and aviation medical literature.

42. Prosecute dental research into aero-otitis resulting from malposition of the lower jaw, aerosinusitis as a cause of dental pain and study of maxillofacial injuries sustained in aircraft accidents.

43. Make studies, based on pathological material and examination of crash scenes, of the fundamental nature of pilot error in the causation of aircraft accidents.

44. Study human factors in emergency aerial escapes from aircraft falling out of control.

45. Make pathological analysis of the relation among forces which cause injuries to personnel and damage to aircraft structure as the result of accidents, with the object of offering recommendations on redesign of aircraft to minimize injuries and fatalities during aircraft accidents.

46. Carry on clinicopathological studies to improve diagnosis and treatment of internal injuries produced by aircraft accidents; also make prolonged follow-up studies of personnel involved in accidents.

47. Make experimental studies of traumatic cerebral injury.

48. Continuously carry on work in evaluation and determination of the physical and psychologic requirements for selection of flyers by correlating all information resulting from research, administrative policy and manpower requirements.

The principal research equipment at the Army Air Forces School of Aviation Medicine includes the following items:

2 Twenty-man low-pressure chambers.

1 Twenty-man refrigerated low-pressure chamber.

3 One-man low-pressure chambers.

1 All-weather room (temperature range − 50°F to + 150°F).

1 Vertical decelerator for small animals.

1 Electroencephalograph.

Electrocardiographs.

Quarters for experimental animals.

Medical library.

Statistical laboratory with Halorith machines.

Machine shop.

Biophysical laboratory for developing and maintaining technical instruments.

Photographic laboratory.

In addition, the clinical facilities of the hospital, with complete diagnostic, therapeutic and surgical equipment are available.

Complete laboratory equipment for basic research in each of the following subjects is available:

Bacteriology	Internal medicine
Physiology	Chemistry
Psychology	Ear, nose and throat
Pathology	Experimental surgery (animal)
Tropical medicine	Neuropsychiatry
Physical education	Pharmacology
Opthalmology (including lens grinding)	

Physiological Section, Proof Division, Eglin Field.

This is included among the facilities of the Army Air Forces Proving Ground Center. It service tests and tactically evaluates equipment which is to be submitted to the Army Air Forces Board for standardization as Army Air Forces equipment. Service testing consists of simulated field use of aero medical and personal equipment, coming cheifly from the Engineering Division, Air Materiel Command, to prove or disprove its value. When approved, equipment is recommended for standardization to the Army Air Forces Board. When design or material is proved unsatisfactory under service conditions, Air Materiel Command, or the submitting agency, is notified and corrections are made. The Physiological Section, Proof Division, is manned by aviation physiologists. The equipment consists of a decompression chamber and a physiology laboratory. Aircraft and other equipment of the Proof Division are available for use in testing.

The Aero Medical Department, Army Air Forces School of Applied Tactics.

In this school are taught combined operations of aviation medicine and aviation tactics to prospective flight surgeons in a thorough course, and to line officers in brief courses. The department operates the Personal Equipment Officers' School. Research has been along lines of field medicine, including survival in the tropics, unit surgeon's duties and staff medical duties. Research facilities consist mainly of operational equipment of the Army Air Forces School of Applied Tactics and the botanical gardens and lush tropical vegetation in parts of Florida.

The Medical Section, Army Air Forces Board

This board has the responsibility of recommending standardization of personal equipment items and medical items peculiar to the Army Air Forces. This office calls on the Aero Medical Department, Army Air Forces School of Applied Tactics, or the Proof Division, for actual testing of equipment.

Central Medical Establishment.

These are small medical research sections organized by overseas air forces, on occasion, for developing and testing equipment and methods to meet problems peculiar to certain theaters. These units have had large responsibility in evolving methods of care of the flyer for their respective air forces. Those in operation during the war were the First Central Medical Establishment; the Second Central Medical Establishment, Far East Air Forces; and the Third Central Medical Establishment, Ninth Air Force. They were manned by flight surgeons, aviation physiologists and personal equipment officers. No great amount of equipment, other than a decompression chamber, has been needed to operate these units. Such an organization in the Occupation Air Force of Germany can accomplish a great deal in evaluating German accomplishments in the war and in utilizing German research men and equipment to complete some of the aero medical research problems which were under way in Germany on V-E day.

Medical Section, Office of Flying Safety.

This section has prepared statistical analyses of reports of aircraft accidents. These studies have been of value in indicating the need for further research and safety training.

Altitude Training Units.

These units in charge of aviation physiologists and equipped with low-pressure chambers, which at one time during the war numbered more than forty, had as their principal duty the indoctrination in use of oxygen equipment of all aircrew members. Opportunity for research was afforded. Resulting accomplishments included much improved knowledge of decompression sickness and anoxia of altitude, streamlined training procedures and suggestions which led to improvements in aircraft oxygen equipment. Altitude training units in the postwar Army Air Forces should continue to be assigned research projects, and the physiologists in these units should have more time for reasearch.

The Personal Equipment Laboratory, Engineering Division, Air Materiel Command.

Although this is not a medical installation, it has done and will continue to do research in the development of personal equipment of an aero medical nature (survival equipment, safety belts, parachutes, flying clothing, etc.). A close working relationship exists between this laboratory and the Aero Medical Laboratory.

SERVICE FUNCTIONS

Those functions which are an aid to aero medical research and which should be amplified during the postwar research program are the following: a central library, publications and motion pictures, statistical departments and liaison activities.

LIBRARY AND PUBLICATIONS

The central library on aviation medicine is gradually being expanded at the School of Aviation Medicine. The library should include most of the pertinent literature, motion pictures and microfilms concerning aviation medicine and allied fields derived from the entire world. Great effort should be made to collect all relevant material published during the war and to obtain all relevant literature as it comes out in the postwar period. The library should be under the direction of a professional librarian. All material should be catalogued; it should be available by loan or by microfilm reproduction to all agencies doing Army Air Forces medical research. Translators should be permanently employed to handle foreign literature.

Abstracting important literature should be a continuous program and these abstracts should be published in the "Air Surgeon's Bulletin." Graduate students or other research personnel should be assigned to the library for temporary duty to prepare reviews of the literature on important current subjects for distribution to interested agencies. A worth-while example of this type of review is a monograph on blast injury, prepared by Templin, of the University of Pennsylvania, which has become a standard reference manual on the subject.

No large, coordinated program such as postwar aero medical research can be carried on at widely separated points without a periodical journal to disseminate ideas and new information. The "Air Surgeon's Bulletin" is a magazine published by the Army Air Forces for distribution to every medical services officer in the Army Air Forces, to certain medical installations in the Army Service Forces and Army Ground Forces where flying personnel are treated, to federal and civilian agencies interested in aviation, to civilian institutions doing research in aviation medicine and to medical college libraries. The magazine is also sent to medical departments of leading commercial airlines, in order that the public may benefit from new developments in aviation medicine, and to research sections of leading aircraft manufacturers so that medical problems will be considered in the design of aircraft. The value of this magazine will be enhanced in peacetime by the printing of abstracts on aviation medicine (as "Biological Abstracts" or "Chemical Abstracts" are published) for dissemination to all agencies carrying on aero medical research. Reviews of the literature of current aero medical problems should be published frequently. The Germans had civilian periodicals on aviation medicine but no official journal.

The Aero Medical Laboratory and the School of Aviation Medicine should make timely revisions of the important manuals and motion pictures which were prepared during the war. These include the following: "Flight Surgeon's Reference File;" AAF Manual 25-2, "Physiology of Flight;" T. O. 00-25-13, "Your Body in Flight;" T. O. 03-50-1, "Use of Oxygen and Oxygen Equipment;" and training film, "Use of Oxygen in Combat."

STATISTICS

Future research in the Army Air Forces by officers with a great diversity of training and experience, and whose assignment to research work may be temporary, calls for supervision of statistical methods so that they will be carried out as they are in biologic research. Statistical departments are already in existence in the Office of the Air Surgeon and at the School of Aviation Medicine. There is need to continue these offices, which have personnel well trained in biometry. These experts suggest methods of performing experiments so that data collected will be valid; they consult on collection of the data and assist in statistical analysis of experiments.

LIAISON

Research laboratories must maintain constant liaison with other service laboratories, civilian and foreign laboratories and, overseas installations. This liaison must be placed in the hands of competent personnel who will be respected by the individuals with whom they are associated.

It is believed that it would be very desirable to maintain liaison with the service and civilian laboratories of the major allies. To accomplish this, the system used by the Royal Air Force in the United States during the war might be adopted, with whatever adjustments that might prove necessary. Liaison positions should be filled by volunteers for 18 to 24 months of duty. In so far as possible, all information should be exchanged through these representatives of the Air Surgeon. Provision should be made for their frequent return to the United States to obtain and impart information and to engage in conversations. If better coordination with the Naval Air Forces is obtained, one liaison officer may serve both forces.

Information from overseas installations should be received in a constant flow. The best method is to depend on such organizations as adequately staffed central medical establishments. If this is not possible, arrangements should be made for frequent visits by personnel of the Army Air Forces laboratories. At times, when problems are encountered which cannot be investigated adequately on the mainland, it will be necessary to establish temporary laboratories in these overseas installations.

The establishment of an Aero Medical Laboratory in a portion of the Kaiser Wilhelm Institute at Heidelberg as a branch of the Aero Medical Laboratory at Wright Field has proved its worth. The foremost German scientists in aviation medicine carry out research under the direction of Army Air Forces medical officers who thus have the benefit of both overseas service and the opportunity of supervising the research of the Germans or of carrying out research on their own.

The most complicated and important liaison is that with civilian organizations. This divides itself into the more formal liaison, such as that maintained with the National Research Council, and the more informal type similar to that which exists normally between civilian laboratories.

Several universities have carried out aero medical research during the war. Most of this work has been done under contract with the Office of Scientific Research and Development and a slight amount under contract with the Army Air Forces. Since the Office of Scientific Research and Development will be disbanded in the near future, new arrangements must be made for research now carried on by civilian organizations. Some of the work can be taken over by the Aero Medical Laboratory and the School of Aviation Medicine. In order to maintain civilian interest and to obtain benefit of the scientific skill available at American universities, most of this research and a great number of new research problems should be carried out by civilian organizations under contract with the Army Air Forces.

Industrial organizations under contract with the Army Air Forces have performed much research in the development of laboratory instruments and personal equipment of an aero medical nature. In many instances this has been a very satisfactory arrangement and should continue in the postwar period.

Due to the close relationship between aviation medicine and new developments in aviation, there must be continued coordination between aero medical institutions and aviation research agencies. The Aero Medical Laboratory is particularly fortunate, as a result of being one of the laboratories of the Engineering Division, Air Materiel Command, to be in close touch with the basic work in aviation which is under way in the following laboratories of the Engineering Division: Aircraft, Communications and Navigation, Equipment, Materials, Personal Equipment, Photographic, Power Plant, Radar, Special Projects, and Technical Data.

There are nonmilitary facilities with which aero medical leaders must maintain close liaison if they hope to establish human tolerances and limitations in time for use of this knowledge in designing new aircraft. These include the National Advisory Committee for Aeronautics, the Massachusetts Institute of Technology, the California Institute of Technology, The Mayo Foundation, Civil Aeronautics Authority and aero medical research facilities maintained by universities such as Ohio State, the Johnson Foundation, the University of California, University of Southern California, Yale University, and the commercial airlines.

In times of peace, there exists a wide gap between the military and civilian scientific worlds. In wartime this gap is bridged because of the necessity for united action and by the fact that the army takes as soldiers many personnel from civilian organizations. The lack of these contacts in peacetime causes the armed forces to lag behind considerably. This situation may be remedied by maintaining within the Army Air Forces a group of scientific personnel who, in addition to carrying on scientific work, can serve as interpreters, ambassadors or catalysts, acquainted with civilian science on the one hand and the armed forces on the other.

It may be argued that the research necessary for the Army Air Forces might be accomplished by civilian organizations and such an argument is valid; however, the military service repeatedly has seen the interest of civilian organizations withdrawn from problems of military interest. This is in part only natural in the United States. The military life here offers major careers for very few. There exists during peacetime an attitude that preparation for war must necessarily result in war. A second factor is that the maintenance of adequate preparedness is expensive; in a rapidly advancing technological age, expensive war machinery must be advanced as new developments replace the old. Since these machines are designed for war, in peacetime they must be abandoned unused. This, on the surface, appears to be uneconomical and military appropriations become difficult to obtain. Military items in the national budget may be reduced or eliminated without apparently affecting the average citizen. These reductions, of course, prohibit the military establishment from developing up-to-the-minute equipment. The change from the intense interest aroused by wartime necessity, to the lack of interest in peacetime, is remarkably rapid and has followed each war. It is unreasonable to believe that a similar situation will not occur in some degree now that World War II is over. It is imperative, therefore, that the Army Air Forces be provided with research personnel who will have a deep and lasting interest in military problems.

TRAINING OF RESEARCH PERSONNEL

To be successful, research must have continuity, and to maintain continuity, new personnel must be trained. Therefore, although the argument resembles that of the chicken and the egg, a research program cannot endure unless continuous training is presented; and to present a wide, continuous training program, a continuous research program must be maintained.

There frequently exists in certain military quarters an attitude which does not allow recognition of the invaluable aid which can be obtained from civilian scientific groups. Frankness, honesty and ability in science are without formal grade or rank but the civilian frequently is forced to deal with military men on bases other than these. This is not attractive to him and is foreign to the atmosphere in which his dealings usually take place; consequently, he refrains from forcing his attention on those who seem not to desire it. All of these difficulties are not insoluble but their solution will require vigorous effort on the part of the military service. It is imperative that only the most highly trained individuals be selected as personnel for postwar aero medical research, since it is necessary virtually to maintain the highest possible research standards. All research personnel must be selected on the basis of aptitude to work with military personnel. The majority of these personnel should fly, particularly those who carry out applied research.

Certain fundamental problems must be kept in mind in discussing the selection of research personnel. These problems are best introduced by a brief statement of what research ought to offer the average worker, as follows:

1. The opportunity to perform whatever research work he himself desires within a field of his own choosing. The research worker is not hampered by broad boundaries but he will resist determinedly any attempts to confine his activities to narrow fields unless he, himself so desires to confine them.

2. The opportunity to work under proper direction and with people similar to himself. It must be remembered that in civilian life, if the interest of the laboratory in which he is working changes, if the director is inadequate, or if the worker is unable to maintain good relations with personnel in the laboratory, he is free to attempt to find a laboratory where his interests mesh better, or where the direction is more to his liking or the personnel are more satisfactory. Accepting a position in the military establishment automatically limits his freedom in this regard.

3. The opportunity to gain recognition for his efforts. This is usually accomplished through the medium of publications, membership in societies, winning of prizes and the like, as well as advance in academic status and salary.

4. The right to govern his own working hours and manner of working. Individuals differ in this and the average research worker will fight against regimentation in this regard.

5. A living wage, one which permits a normal opportunity to secure a decent living, some provision for the future and opportunity to refrain from work in order to pursue further studies.

6. The chance to gain academic degrees; a sort of corollary to number 3.

If these conditions are examined carefully it is apparent that the establishment of some of them under military auspices can be accomplished only with difficulty. However, they must be established if the Army Air Forces is to attract the proper type of personnel.

Although the desirable conditions mentioned above do not in themselves produce research personnel, they are those which, through long, long years of experience, have been shown to be the most conducive to good research. Remuneration and opportunities for graduate training (numbers 5 and 6 of the above mentioned list) deserve more detailed discussion, since the Army Air Forces must develop a new policy before research men will consider conditions favorable for joining the service.

Industry has succeeded in attracting research personnel, in spite of manifest difficulties, by offering salaries double and treble those to be found in academic life. Especially to the worker engaged in pure science, this is the greatest attraction of industrial work. The problem of attracting these personnel to the military service is a similar one. The old arguments of regular increases in grade and in pay, and eventual retirement pay, are nullified by existing industrial policies which include a munificence that often makes the material rewards of military service appear small in comparison.

What can be done in this regard? The answer is at once relatively simple and relatively difficult. During time of war, physicians are admitted to the army with relative grade, in accordance with their training and experience in certain specialties. But research workers have comparable training and experience. Solution of the problem then lies in recognition of the fact that research training is the equivalent of training in the medical specialties and research experience is the equivalent of experience in practice of a medical specialty. Once this has been recognized, then it should prove relatively simple to commission research personnel in field grades.

The primary deterrent to commissioning research personnel in field grades lies in the regulation regarding the commissioning of officers in the regular army according to age. This rule entirely ignores ability and would prevent the commissioning of young, vigorous individuals sorely needed in the military service. As already has been demonstrated, there will exist for some time to come severe competition for the services of such individuals. It will be necessary therefore to revise thoroughly the present standards for commissioning certain officers in order to secure the proper research personnel.

The research worker's recompense also includes opportunities for additional study and training. Assuming that the military services desire to maintain the highest possible standards of research, it is then axiomatic that its workers must be given every opportunity for regular periods of study and training in this country and overseas to supplement their formal education and laboratory experience. This has been recognized in academic circles and has led to the sabbatical year. Because interests change rapidly and science moves apace, it is imperative that frequent sabbatical leaves be granted and encouraged. An appropriate schedule is one year in every five. Only in this manner will the personnel be enabled to maintain the desired standards and be acquainted with climatic and other conditions all over the world.

In the university laboratories there usually will be found a relatively large number of graduate students who are performing research as a part of their graduate training. Aside from the rewards which they attain in doing research, they are also obtaining academic recognition in the form of a graduate degree. They represent the sole source of future research personnel. Some of them will go on into industrial positions; others will remain in academic institutions. Regardless of their final destination, they have two immediate goals: first, training themselves in research, and, second, obtaining a graduate degree, recognition of the completion of their first stage of training.

The problem facing the Army Air Forces is not identical with that in university laboratories because it is not absolutely necessary (from the standpoint of obtaining personnel when needed), that graduate students or their equivalent be trained in the laboratories. Theoretically it should be possible to commission already trained men as replacements. Many arguments both for and against training research personnel in service laboratories can be presented and they parallel in part arguments concerning an Army Medical School. There is, however, one factor which outweighs all others and which differentiates the two problems; namely, that to have students in a laboratory is stimulating. The students bring fresh points of view which are very helpful and they aid in keeping the staff mentally "on its toes."

Since there are not now in the regular army sufficient trained personnel to operate the laboratories, it will be necessary, at least initially, to obtain already trained individuals. The problem then arises as to how subsequent personnel will be acquired. There are five possibilities:

1. Commission individuals already trained.
2. Commission individuals and then sponsor their training in civilian laboratories.
3. Train military personnel in military laboratories.
4. Affiliate Army Air Forces research laboratories with universities.
5. Authorize an adequate table of organization for Civil Service research workers.

The first possibility requires no additional discussion.

The second possibility, that of sponsoring the training of commissioned personnel in civilian laboratories, is deserving of extended discussion. Two methods of selecting such individuals are available. First is the method of selecting promising civilians, commissioning them and sponsoring their training. This would mean supporting a person about whose capabilities information was incomplete in many instances and the success of such a program would depend largely on how carefully personnel was selected. That selection can be done well is evidenced by the number of individuals who are successfully chosen for fellowships and scholarships. In addition, even if some of these individuals did not develop as research personnel, they would be valuable individuals to the military service, since they would be well indoctrinated in the scientific method, which is applicable to the practice of medicine in any of its phases. Such a system might be extended to reserve officers, too, with the understanding that they would serve with the armed forces for a given number of years in exchange for their training.

The second method under the second possibility (sponsoring the training of commissioned personnel in civilian laboratories) is patterned after the method currently in use in the Air Materiel Command. In that command, large groups of graduate engineers are given an extended course of training, with the understanding that they will then serve at least two years with the Air Materiel Command. From among the top members of these classes are selected several individuals who are sent to civilian institutions for postgraduate training, in many instances leading to the degree of Doctor of Philosophy in Engineering. Their education is sponsored in return for a stated number of years of service. On completion of their education, they are then employed in the Air Materiel Command in accordance with their training. Such a screening method and system of postgraduate education is equally applicable to the problem of selecting and training medical research personnel, especially in view of the precedent established in the Air Materiel Command.

The third possibility named in the list which appeared in a previous paragraph, that of training research personnel in military laboratories, hinges on the capabilities of the staff of the laboratories. If the personnel are of the highest caliber, then it should be feasible to train others; if they are not of the highest caliber, then the system would assure only mediocrity in perpetuity. A very real disadvantage of this system is that it interferes with the introduction of new blood into the laboratories whereas the method of training described under both methods of the second possibility would introduce new points of view because the personnel would be trained in several different laboratories. There is no reason, however, why the methods suggested in both the second and third possibilities could not be instituted. The selection of individuals to be trained under either system should be equally rigid and should be left to professional personnel.

Should the third possibility be finally decided on as the most desirable, then it would be well to attempt to give the personnel some sort of academic recognition. It is doubtful that the service laboratories would be accredited to grant academic degrees. However, if the laboratories were associated with universities (the fourth possibility) it might be possible for the universities to recognize the training as equivalent to its own. In this way, on an exchange basis, the individual might obtain his advanced degree from an accredited university.

The association of an Army Air Forces medical research laboratory with a university would make members of the faculty of the university available for use as consultants, and professors could act in this capacity without going on active duty. The

German Air Force commissioned many of Germany's leading scientists and never called them to active duty. The practice proved successful, since these prominent men felt a sense of duty toward the Luftwaffe, acted as consultants, gave lectures to service men and recommended for appointment qualified personnel from among their students.

University professors could spend summer vacations, or a year of sabbatical leave, on active duty as commissioned officers to work on previously assigned research problems. Leading students who performed their postgraduate research as a project in an Army Air Forces laboratory could be commissioned in the regular army or the reserve, thus providing better selection of personnel and a backlog of scientists in case of emergency.

If service laboratories become associated with universities and apply the policies of their associated universities regarding academic freedom, some of the problems which make research workers hesitant to join the service would be solved. There are numerous possibilities. A precedent exists in the successful association of the British Army School of Tropical Medicine with the University of London.

The fifth possibility listed a few paragraphs earlier, that of authorizing an adequate table of organization for Civil Service research workers, already has been successful for aeronautical engineers in the Engineering Division, Air Materiel Command. The bulk of research on aviation carried out in peacetime by the Air Forces was accomplished by civilian scientists at Wright Field. Aero medical research recently made progress along this line when the Psychological Branch, Aero Medical Laboratory, was set up with a table of organization authorizing several high professional civil service ratings. One or two high professional ratings to a laboratory is not enough. It is necessary for each department to have so many highly qualified persons that they establish the quality of the organization. Such a program would attract a high type of personnel, not only as a result of the good salaries but due also to the high scientific reputation of a laboratory which employs widely known persons. If such personnel could be given the privileges of the officers club and other such privileges at Army Air Forces installations both good feeling and liaison would be improved.

An additional procedure which deserves emphasis is the commissioning of Civil Service research men in the reserve. This would be an added bond to hold their allegiance to the Army Air Forces; it would make it possible for them to go on active duty when a project called for an investigator whose position carried the influence of officer status (example: study of a number of pilot officers). Moreover, civil workers could advance in grade sufficiently to hold responsible positions in case of wartime emergency.

INDOCTRINATION, EQUIPMENT, NUTRITION AND SANITATION

During the past war, one of the great services performed by the flight surgeon and aviation physiologist for flight crews was presentation of the indoctrination program through the altitude training units. German flight surgeons have been unanimous in their opinion that the average American flyer had knowledge of aviation medicine that was far superior to that possessed by some of their physicians. Originally, this program specialized in the use of oxygen and emphasized the possible incidence of bends at altitudes above 30,000 ft. As time progressed, the program extended to include other subjects, such as: care of personal flying clothing; protection against heat and cold; use of parachutes; use of air-sea rescue equipment; survival on the sea, in the jungle and in the arctic; use of fire-fighting equipment and use of radio intercommunication equipment at altitude. Simultaneously, the indoctrination program was a constant source of information on requirements of the design for, and on the effectiveness of, flying equipment for the Air Materiel Command. In the postwar period, indoctrinational procedures should be continued on a reduced scale throughout the Army Air Forces so that the flying personnel will be acquainted, by actual use, with new equipment as it is developed; for instance, the ejection seat.

HOSPITAL AND DISPENSARY EQUIPMENT

The Army Air Forces hospital and dispensary equipment for field use must be reorganized and further developed. Development will include the planning of housing facilities for field installations of both hospital and dispensary, so that a unit can be transported by air and set up with the least practicable delay. Also, work must be done on medical field equipment and supplies such as chests, medical and surgical ward equipment, administrative facilities, laboratory facilities and dental equipment. First aid kits and other individual airplane ambulance or rescue kits which are peculiar to the Army Air Forces must be the object of continued development. A mobile dental unit is represented in Fig. 48.

NUTRITION

Adequate nutrition is a well recognized essential for good health and morale and hence is important for the precise performance required in military flying. Both the nutritional value and the tasteful presentation of the food are important. These factors must be considered for regular meals as well as for lunches served while in flight. The Army Air Forces should consider: (1) source of foodstuffs (including hydroponics); (2) preparation of foodstuffs, considering nutrition, therapeutics and palatability; (3) feeding of persons while in flight; (4) special dietary considerations in aviation; (5) emergency sources and preparation of food.

World areas should be surveyed for their potentialities as sources of the various types of foodstuffs. When all types are not available locally in adequate quantities, methods and plans should be made for either transporting needed foods to the areas which require them, or growing the items locally. Methods of handling and preparing locally grown foodstuffs for regular meals and for feeding persons when in flight should be worked out so that any area could be, in so far as possible, self-supporting.

The probability is very great that an adequate diet for ground personnel is also adequate for flying personnel. This hypothesis should be tested, however, before being accepted as true.

Since flyers are likely to find themselves landing, at times, at places other than their destination, it is required that information as to possible sources of, and methods of palatable preparation of foodstuffs be compiled. This compilation should include items such as plankton not originally included in the diet or used as food.

Hydroponics, as practiced by the Army Air Forces, is soilless plant culture for the purpose of supplying fresh vegetables for personnel stationed in regions where fresh vegetables are not locally available, or are not available within transportable distance.

The future program calls for installation and operation of hydroponics gardens at air bases operating under the conditions just described. This calls for concomitant experimentation at such bases to determine both the best varieties of vegetables for the local climate and the best cultural practices.

Research should continue on several questions. (1) Soilless culture of plants needs simplification. Research which is under way gives promise that ion-exchange resins can be mixed with the plant-supporting aggregate so that adequate mineral nutrition of the plant can be obtained by irrigation of the bed with either water or a highly simplified nutrient solution. Perfection of this would make soilless culture much more nearly foolproof. (2) Engineering research should be conducted on construction of beds and irrigation systems. This involves perfection and standardization of tanks, pumps, sumps, valves and beds to simplify operation, and decrease cost of installation and operation. (3) Studies should be continued on the suitability of various earth aggregates for use as plant-supporting media. Thus the use of locally available materials can be assured wherever possible. (4) It is hoped that facilities will be made available for study of environmental control for growing vegetables in regions where the climate is unsuitable for vegetable gardens. Present developments require a suitable climate. The probability of having permanent bases in regions climatically unsuitable for agriculture (in the far north), indicates the desirability of having procedures perfected for hothouse culture under artificial light and temperature control.

SANITATION

Many problems of sanitation peculiar to aviation are new to military medicine and, in order to be adequately solved, require research by Army Air Forces personnel. Some problems which require further investigation are as follows: sanitation equipment and procedures for advance airborne tactical units such as fighter squadrons; care of airborne food supplies in flight (meat and perishable vegetables); care of animals in flight; control of respiratory disease to minimize lost flying time (this has been mentioned previously); and sanitation measures for very large continental and intercontinental passenger aircraft.

The brief time required for transoceanic flights makes possible the arrival in the United States of individuals harboring communicable diseases in the asymptomatic, incubation stage and of insects capable of transmitting disease. Research on this problem applicable to the Army Air Forces should be coordinated with federal and international agencies responsible for regulations and laws on a world-wide system of quarantine. This system of quarantine could well be based on a system of disease intelligence, use of an international travel-log and immunization record for each traveller and recognition of the definite protection afforded by modern methods of immunization.

The advent of DDT has opened a wide field for dissemination of powerful insecticides from aircraft. This calls for combined investigations by aeronatuical engineers, entomologists, sanitary engineers and medical men. Research along this line also calls for investigations of disinsectization of aircraft, camp sites and permanent installations.

APPENDIX

AERO MEDICAL ASPECTS OF CABIN PRESSURIZATION for MILITARY AND COMMERCIAL AIRCRAFT

Introduction

During the recent war, technical advances toward realization of high-altitude flight have been many. The three most important on the engineering side are the development of the turbosupercharger and jet-propulsion engines, and the evolution of the laminar flow wing. Now within reach are flights by military aircraft well above limits tolerated by humans breathing pure oxygen. Sustained flights at high altitude are also possible for both military and commercial aircraft. Parallel with these rapid engineering advances, methods for maintaining aircrew efficiency and safety as well as passenger comfort must be continually developed. The most logical step in this direction taken by the aircraft designers has been cabin pressurization. It is the purpose of the present communication to present the aero medical requirements for health, comfort, efficiency and safety of air crews and passengers while flying in pressurized cabin aircraft.

Physiological Requirements in Flight

It is a well accepted fact, based on long flying and operational experience, that optimal efficiency and safety of air crews requires the supplementary use of oxygen above 10,000 ft for daytime flight and above 5000 ft for night flight. Flight without oxygen above these levels will result in increasing degrees of anoxia and in progressive loss of judgment and flying efficiency. The demand oxygen system now used by the Army Air Forces is designed to increase automatically the concentration of oxygen from that of pure air at 5000 ft to 100% oxygen at 33,000 ft, so that the atmosphere in the lungs remains like that which is obtained at 5000 ft or below. Above 33,000 ft, the margin of safety when using pure oxygen decreases steadily to 40,000 ft, at which altitude, even when pure oxygen is breathed, the atmosphere in the lungs is equivalent to that which obtains at 10,000 ft when the subject is breathing air. Above 40,000 ft the 10,000 ft equivalent can be maintained only by the use of pressure breathing. The top level now recommended for continuous use of pressure breathing is 42,000 ft with 6.5 in. of water positive pressure, which combination results in an atmosphere in the lungs corresponding to that when air is breathed at 10,000 ft. Under emergency conditions for short periods of time, pressure breathing may be used to 50,000 ft with 12 in. of water positive pressure, corresponding to 16,000 ft air equivalent. For emergency flights above 50,000 ft, a lightweight pressure suit would be required to reduce the equivalent altitude about the flier to 40,000 ft or below.

Statements similar to those presented above apply to the continuous flow type oxygen system. However, where the demand system supplies the necessary supplementary oxygen for all levels of exercise, the level of flow in the former system must be increased as the level of exercise increases in order to maintain a fixed safety level. At altitudes above 25,000 ft, for the same degree of safety the demand system is very much more economical in the use of oxygen than is the continuous flow system.

Aeroembolism, which manifests itself in the form of bends, of chokes, and of skin and neurological symptoms, rarely occurs below 25,000 ft. However, it becomes increasingly significant as the altitude increases above 30,000 ft. For 1 hr exposure or less at 35,000 ft, 1 person in 10 would likely be incapacitated; 1 in 4 at 40,000 ft. Very few individuals can stay more than 20 min above 40,000 ft without suffering from some form of aeroembolism. The incidence of aeroembolism is increased by exercise on the part of aircrews. The incidence of aeroembolism can be greatly reduced by prebreathing 100% oxygen for one-half hour before flight and remaining on 100% oxygen for the entire flight. There is a small percentage of flying personnel for whom oxygen prebreathing gives no protection from aeroembolism, who suffer regularly on flight above 35,000 ft, and who should be disqualified for high-altitude flight.

At altitudes below 10,000 ft, proficiency in night vision and dark adaptation are extremely important considerations, as they are greatly affected by mild degrees of anoxia. For example, to maintain an equivalent stimulus on, and response from, the retina the percentage of increase in light intensity for various altitudes is as follows:

Sea Level	0%
5,000 ft	23%
10,000 ft	59%
12,000 ft	78%
14,000 ft	101%
16,000 ft	140%

Although use of high concentrations of oxygen from sea level up is desirable for the preservation of night vision, the small loss in night visual efficiency at 5000 ft, is the maximum allowable for effective operational purposes. Above 5000 ft, use of oxygen is a definite requirement to preserve night vision. A second visual phenomenon associated with mild anoxia is the dimming of peripheral vision when illumination is poor. Both Hecht and Livingston have shown that this effect becomes increasingly serious above 6000 ft.

Levels of Cabin Pressurization

There are essentially three types of human design requirements for use of cabin pressurization:

(1) Pressure within the cabin shall be maintained at levels where continuous use of oxygen equipment will not be needed.

(2) When oxygen is used continuously, pressure within the cabin shall be maintained at a level low enough to prevent incidence of aeroembolism.

(3) For flights above 40,000 ft sufficient pressurization shall be used to obviate the use of pressure breathing and the risk of mild anoxia above 42,000 ft with pressure breathing.

To meet these human requirements the engineer must stress his cabin fuselage to take the necessary differential pressure. The maximum required differential pressure is set by the operational ceiling of the aircraft (in contradistinction to the service ceiling).

The first of the above requirements is used by the Army Air Forces in the design of its pressurized bombers. For example, the B-29 is designed for a 6.55 psi maximum operating differential which allows an atmosphere within the cabin (cabin altitude) equivalent to that found at 8000 ft when the aircraft is at an actual altitude of 30,000 ft or a 10,000 ft-cabin altitude at 35,000 ft.

The second of the above requirements is followed in the design of pressurized fighters. The differential pressure most frequently chosen by the aircraft designers is 2.75 psi, which allows a 25,000-ft cabin altitude at 40,000 ft or a 30,000 ft-cabin altitude at 50,000 ft.

Choice of any design cabin differentials between the 2.75 psi and the 6.55 psi value, the aircraft engineer will quickly note, does not increase the tactical efficiency of aircrews when flights above 30,000 ft are possible. A value of 4.0 psi at 30,000 ft would result in a 15,000-ft cabin altitude at which level oxygen would have to be used continuously. At 40,000 ft a 2.75 psi differential is adequate for the second requirement above; the possible saving in oxygen consumption using a 4.0 psi differential instead of a 2.75 psi would be balanced by the increased loading of the cabin superchargers and heavier construction of the cabin walls and pressure seals.

The third requirement, listed above, would be used only under emergency or combat conditions, when other hazards, such as explosive decompression (which will be discussed below), prevent the meeting of either of the first two requirements.

In Fig. 1, the various factors presented in the two sections above are outlined to indicate their interrelationship.

Explosive Decompression

The principle hazard to aircrews of tactical aircraft, when operating with pressurized cabins, is the possible damage caused by the expansion of internal body gases as a result of explosive or rapid decompression of the cabin itself. The failure of the cabin structure may have been caused by enemy gunfire. The degree of explosive decompression that one can withstand safety is determined by the extent and the rate of expansion of the internal body gases such as are found in the stomach, intestines, and lungs. The experimental studies of Major H. M. Sweeney, of the Aero Medical Laboratory, Wright Field, summarized in detail in the October, 1944 issue of the Air Surgeon's Bulletin, have shown that the two most significant factors associated with sudden decompression are the time of decompression (t) and the relative expansion of internal gases (RGE), which is evaluated by the following relation:

$$\text{RGE} = (\text{Pc} - 0.91)/(\text{Pa} - 0.91), \qquad (1)$$

where

Pc = Cabin pressure before decompression in psi

Pa = Ambient or final pressure after decompression in psi

and

0.91 = Vapor pressure of water at body temperature, 98.6°F in psi.

In particular, it was demonstrated in the above series of experiments that for very rapid or instantaneous decompressions (approx. 0.01 sec or less) a relative gas expansion of 2.3 approached the maximum tolerance. As the time of decompression increases, the increased pressure of expanding gases has time to be absorbed partially by neighboring tissues, and the gases can escape from the body; thus the maximum tolerance RGE would increase. In Fig. 2, the maximum tolerance decompression conditions, observed for human subjects, have been plotted in terms of RGE and the time of decompression, t. A straight line, drawn between the topmost series of experiments, is described by the equation

$$\text{RGE (Max)} = 2.1 + 17.0\,t \qquad (2)$$

This line defines the borderline decompression conditions between the zone of safety, determined by adequate laboratory experience, and a zone of uncertainty, in which experimental data either are limited or are unknown. The line described by equation (2) can be considered by the aircraft engineer a maximum design limit for tolerable decompression that includes a margin of safety sufficient for military operations. It should be added at this point that the probability well exists that certain conditions above this line are tolerable; however, the present limit is proposed until new data are available for which a new design line can be drawn.

From Fliegner's equations for the flow of air from an orifice, it can be shown that the time of decompression, t, in seconds, may be described with sufficient accuracy by the equation:

$$t = 0.22 + (Vc/A) + \sqrt{(Pc - Pa)/Pa}, \qquad (3)$$

where

Vc = Volume of pressurized cabin in cu ft

A = Cross sectional area of hole caused by structural failure in sq in.

and

Pc and Pa are as before in equation (1).

A preliminary test of this equation by an actual decompression in flight indicates that, because of a possible orifice coefficient less than unity, the observed times of decompression may be longer than calculated above. For the present analysis an equation giving the probable minimum decompression time for a given set of design factors is desirable.

Combining (2) and (3) the maximum tolerable relative expansion of internal gases is given by the relation

$$\text{RGE (Max)} = 2.1 + 3.8\,(Vc/A)\sqrt{(Pc - Pa)/Pa} \qquad (4)$$

The criterion of safety for an aircrew during any decompression in a pressurized cabin aircraft is that the RGE (Max) as calculated by (4) is greater or equal to RGE as calculated by (1). When RGE calculated by (1) exceeds RGE (Max), dangerous or questionable conditions exist. These criteria for safety should be applied at the maximum service ceiling of the aircraft under consideration. Under these circumstances, it can be demonstrated that flight conditions below the service ceiling will also satisfy the criteria with a further margin of safety.

The factor A, the area of the fuselage surface lost by structural failure caused by enemy action, must in the long run be evaluated by gunfire tests. For preliminary design purposes it can be assumed to be the area of a jettisonable bubble canopy, a nose section, or an escape hatch door. Practical application of the above criteria shows that:

a. For pressurized fighter aircraft where the cross-sectional area of the bubble caopy (approx. 600 sq in.) is large in relation to the cockpit volume (50 cu ft) the limit of the zone of safety is described by a choice of cabin altitudes or differential cabin pressures so that for any flight altitude the RGE does not exceed 2.3.

b. For heavy bombardment aircraft (2000 cu ft and up) flying with a cabin differential of 6.55 psi at 40,000 ft, the largest allowable explosive orifice A is 7000 sq in. or a hole 8 ft in diameter. Since this hole is 10 times larger than that normally expected from enemy action decompression may, as a rule, be considered a minor hazard for this type aircraft.

c. The greatest variability in allowable operating conditions occurs in medium bombardment aircraft with cabin volumes in the range of from 200 to 400 cu ft. This is illustrated in the following typical example for an aircraft with a cabin volume of 350 cu ft, flying at 45,000 ft.

(1) For loss of a jettisonable bubble canopy (2000 sq in), RGE(Max) is 2.75 and maximum allowable cabin differential is 2.15 psi.

(2) For loss of a nose section (1000 sq in.) RGE(Max) is 3.85 and allowable differential is 3.5 psi.

(3) For loss of an escape hatch (600 sq in.) RGE(Max) is 5.7 and the allowable differential is 5.7 psi.

In Fig. 1, the line for an RGE of 2.3 applicable to fighter aircraft has been drawn to indicate the limit of safe conditions for explosive decompression. Examination of this figure will show that for fighter aircraft in combat above 50,000 ft the choice has to be made between the dangers of explosive decompression or the increasing degrees of anoxia while using pressure-breathing oxygen.

Above 63,000 ft, where blood boils normally, the above criteria indicates that the hazard of explosive decompression is infinitely great. Therefore, above 63,000 ft, there are no conditions of cabin pressurization that can be used to avoid this hazard. The only apparent solution to this dilemma is to develop some type of elastic or rigid clothing to prevent overdistension of the body during the decompression. At present, one of the most serious unsolved problems of flight at extremely high altitudes is that of human survival in a vacuum.

Aural and Sinus Phenomena

From decompression experiments on human subjects it has been observed that the pressure in the middle ear is relieved automatically for very rapid changes in outside pressure. A normal ear can easily adjust itself to a rate of pressure loss of 100 psi/sec without any aural or pressure sensation at all to the subject. This statement is not true for air-crew members with colds and respiratory infections. A passenger with an occluded sinus would suffer severely from pain when either the volume or the pressure of the trapped gases increased as little as 30% regardless of the rate of decompression. In the design of cabin pressure regulators, the Army Air Forces requires that the drop in cabin pressure be limited to 1 psi/sec, a value that can be considered conservative in the light of explosive decompression data now available.

With a rise in cabin pressure, the negative pressure in the middle ear can be relieved only by a voluntary effort on the part of the aircrew. The ability to clear ears varies greatly with the individual and with his flying experience. For military aircraft the rate of rise of cabin pressure is limited by pressure control to 1 psi/min (approx. 2500 ft/min) provided the rate of dive of the aircraft itself does not exceed this value. For commercial aircraft, past experience has shown that 0.10 psi/min or 300 ft/min at sea level is the most comfortable rate for the average passenger. Recently it was shown at the School of Aviation Medicine that, when conditions within the cabin were caused to fluctuate between those which were obtained at 7700 ft and at 8300 ft, at a rate of 600 ft/min or 0.25 psi/min, sensation on the ear drums was so small as not even to disturb sleep. This result will indicate the required constancy in the desired controls.

When the cabin controls are fitted with a rate of climb and descent adjustment, discomfort to the passenger can be reduced to the minimum. With such a control it would be possible to maintain in the cabin a simulated rate of descent lower than that of the plane itself, and thus an actual rapid descent to an airport would be minimized.

Safety Design of Pressure Cabin Aircraft

When a side sighting blister is lost in the B-29, the decompression time has been determined by firing tests to be approximately 1 sec for the full operating differential of 6.55 psi and cabin volume of 2200 cu ft. During this second, approximately 3500 hp is expended. From the safety viewpoint it is essential that this energy does not reappear in the form of flying debris, such as loose items of personal equipment. During a decompression in the B-29, air velocities as high as 140 mph have been observed momentarily in the interconnecting tunnel. A flier in the tunnel at the moment of decompression would be ejected with very considerable force. Also, the rush of air through the broken blister has sufficient directed energy to blow a gunner overboard if he isn't properly secured to his station by a safety belt.

With proper indoctrination and training in the potential hazards of cabin pressurization, accidents such as those described above for the B-29 are of negligible tactical significance. However, the lessons that can be applied to passenger aircraft are obvious. These are: (a) Restricted passageways between compartments should be avoided. This precaution is especially important as the size of the aircraft increases. (b) Regular exits should have safety harnesses or nets across the inner side during flight to prevent passengers and crews from being accidently blown overboard.

Another important lesson from the operational experiences of the B-29 is that the use of single-layer plexiglas in pressurized aircraft is an undesirable practice and should be avoided wherever possible. Since the single layer plexiglas blisters of the B-29 were replaced by the laminated type about a year ago, there has not been a single report of a blister failure of this type from operational causes. In addition to the use of laminated plexiglas, another desirable practice is to avoid the use of very large plexiglas sections without segmentation.

The increasing tendency to use formed plexiglas in the design of nose sections and canopies of pressurized aircraft leads to a word of precaution. Until now, the visual properties of plexiglas canopies and sections have not been as good as those of grade B plate glass. Where the line-of-sight is greater than 55° to the normal to the plexiglas surface, serious errors in depth perception and loss of acuity and of distant vision can be expected. Use of flat laminated plate glass of grade A optical quality is a requirement for crew compartments in passenger aircraft. For tactical aircraft where speed is required, a compromise, using curved plastic, is necessary. However, the plastic industries can well improve the visual properties of viewing sections.

Ideally, all exit hatches should open outwards in tactical aircraft. At the present time this is true for fighter aircraft. When space for the air crews is restricted, as it would be, for example, in medium bombardment aircraft of from 300 to 400 cu ft volume, outward opening of hatches is also desirable. For the heavy bomber aircraft, such as the B-29, and for passenger aircraft, where cabin space is not at such a premium, inward opening doors are allowable. A small residual cabin pressure can preclude the use of inward opening doors in an emergency. In actual practice, it should be possible to open all inward-opening emergency doors or exits by simple mechanical means against at least a 0.5 psi inside pressure.

Escape from high-speed aircraft is becoming of more concern to the aircraft designer and to flying personnel. Recently it has been revealed that the German Air Force has developed an ejection seat propelled by a small gunpowder charge. This type of seat at the present time appears to be the most practical approach to an escape method from high-speed aircraft. When an ejection seat is used in pressurized-cabin aircraft, the canopy must be ejected simultaneously with the seat causing the pilot or air crew to experience a rapid or even explosive decompression. It is, therefore, important that a differential pressure in the cabin be selected by an RGE control so that the safety criteria for decompression, as outlined above, always apply. In particular for fighter aircraft for flight altitudes above 38,000 ft (Fig. 1) the RGE control of 2.3 should overide the 2.75 differential control and so keep the cabin safe for rapid escape without risk of unconsciousness for a pilot from a too severe explosive decompression. This statement should apply for all flight conditions and not be limited to combat conditions alone.

Emergency Procedures in Pressure-Cabin Aircraft

There are two critical points in the oxygen altitude scale that require warning for the aircrewmen. The first is at 10,000 ft, a warning to put on oxygen equipment. The second is at 40,000 ft, above which pressure breathing should be used. All tactical pressurized-cabin aircraft use a cabin-altitude warning switch to indicate these critical levels by means of a horn or pilot light. At the present time, all fighters and bombers of the Army Air Forces have the demand oxygen system. Those capable of flight above 35,000 ft are equipped with the pressure demand system.

A factor that must be given serious consideration while flying in pressure-cabin aircraft is the duration of useful consciousness for a pilot after decompression. Above 30,000 ft, the time of useful consciousness becomes increasingly less. Skill and practice will, therefore, be required by the pilot to connect his oxygen system. The allowable time for emergency action is illustrated in Fig. 3. The curves give the time of useful consciousness with and without previous use of oxygen. On the basis of these curves it may be concluded that all crews of pressure-cabin tactical aircraft in combat areas should use their oxygen masks for flights above 30,000 ft.

Below 30,000 ft the loss of flying efficiency as a result of a sudden decompression of the cabin is a matter of minutes rather than seconds. Curves indicating these tolerance limits are presented in Fig. 4. Below 25,000 ft the limits vary greatly with individual tolerance to anoxia and may be considered in the present chart as indicating a trend rather than a basis for design or operation.

Use of cabin pressurization serves to reduce the required oxygen capacity rather than to eliminate the need for the system. Cargo and passenger aircraft with pressure cabins, such as the Constellation (C-69) and Strato Cruiser (C-97), have continuous flow systems for both the passengers and crews.

It would be a very fallacious policy for designers and engineers to plan, for postwar commercial use, pressure-cabin aircraft without oxygen systems, when the danger from anoxia to passengers and aircrews at altitudes above 10,000 ft is realized. Although, for the crew, descent from 20,000 ft to safe altitudes is sometimes possible with safety, occasions may arise when weather conditions preclude sudden lowering of altitude. Under these conditions, the danger to crew and passengers is serious. An important safety rule for all pressure-cabin aircraft is that supplementary oxygen must be available at all altitudes when flights above 10,000 ft are made. Present-type continuous flow oxygen systems, such as are used in the C-69, weigh only 225 lb and cause a weight penalty of approximately 3-1/2 lb per passenger and crew member. This weight penalty may be reduced by use of high-pressure supply oxygen or of liquid supply oxygen. A new type of emergency system which is showing considerable promise experimentally is a chemical oxygen generator using superoxide or perchlorate. Walk-around oxygen bottles for stewardesses and crew members will also be necessary emergency items. Finally, the weight penalty of oxygen equipment for commercial aircraft as safety insurance is very small compared to the pay load and certainly small compared to the 1200 lb now carried in transocean flights for life-raft and fire-protective equipment.

Use of oxygen supplied by continuous-flow systems below 18,000 ft does not require any skill or indoctrination of the passenger. Above 18,000 ft, it may be necessary to have an oxygen mask drill for passengers in pressure-cabin aircraft much the same as life-boat drills are held on shipboard. Emergencies, caused by loss of cabin pressure above 25,000 ft, will require quick donning of oxygen equipment by crew and passengers, as the time reserve for useful consciousness is approximately 4 min. An additional emergency consideration above 25,000 ft is the possibility that aeroembolism may occur in some passenger or crew member. As a general practice, plane crew, including stewardesses, must be thoroughly indoctrinated in low-pressure chambers.

At this point it should be noted that the current Civil Aeronautics Board Regulation (Amendment No. 41.23, dated 27 June 1945, effective 1 August 1945) requires an emergency oxygen supply for flight in pressure-cabin aircraft above 18,000 ft for the crew but not for the passengers. This regulation would, therefore, fall far short of the safety requirement for care of passengers outlined in the previous sections.

Comfort in Pressure-Cabin Aircraft

At the present time there are very few actual flight data on comfort requirements in pressure-cabin aircraft that give a real basis for a clear statement of design requirements. In general, the factors that must be considered are: (a) temperature and humidity; (b) ventilation; (c) sound control; and (d) choice of isobaric.

Figure 5 illustrates the human comfort zone and the tolerance levels for hot and cold temperature for aircrews and passengers dressed in ordinary everyday clothes. The comfort and tolerance levels are defined by the environmental temperature, which may be either the dry-bulb temperature or the resultant temperature when radiation effects are considered, and the absolute vapor pressure of the environment. It will be noted that in the warm ranges humidity plays an important role in comfort while toward the cold range its effect is negligible. The air motion equivalent for this chart is 200 linear ft/min.

The ventilation requirement in a pressure-cabin aircraft must be sufficient, first, to maintain the necessary cabin temperature when either heating or cooling is required; and secondly, to remove odors, CO_2, and noxious gases. There are three types of ventilation that may be used in pressure-cabin aircraft. The conventional type, a ram source directed into the cabin from the slipstream, is called the auxiliary ventilation system and would be used only in an emergency or when pressurization is not used. With pressurization, the air from the supercharger acts as the main ventilation source. In bombardment and fighter aircraft this source of ventilation may amount from 70 to 100 cu ft per person, which is more than adequate for the removal of disagreeable odors. For passenger aircraft the ventilated air from the superchargers can drop as low as from 4 to 6 cu ft per person. Although this latter value is sufficient to remove carbon dioxide, it often is insufficient to keep the odor level down. Under these circumstances, recirculation of air through air filters and deodorizers may be necessary for comfort. If the experiences of the railroads in conditioning their pullman and dining cars is of any value in aircraft, the total ventilation in aircraft should be at least 10 cu ft per person for sections where smoking is not permitted and 20 cu ft per person for compartments where smoking is allowed. Deodorization is a specially important consideration if patients are carried for long periods in flight. However, there are no quantitative data available to specify this requirement. For completeness, it should be noted that a part of the ventilated air from the superchargers must be used for defrosting and preventing condensation on windows. Since with large passenger loads, dew points as high as 50°F can be expected where ventilation is not used, proper insulating methods must be carefully chosen.

Sound control in pressurized-cabin aircraft is no more difficult a problem than for conventional aircraft and in some respects may be easier. Preliminary information to date indicates that pressurization tends to remove noise entirely from the high spectral region and confine the noise level to frequencies below 1200 c.

Aside from the effect of altitude on night and peripheral vision noted above, there are other considerations for maintaining isobaric cabins at the 5000 ft level or lower. Comfort may be defined as the state in which one is unconscious of adaption to his environment. Discomfort, on the other hand, implies consciousness of the accommodative processes which are being made by the body. Discomfort can extend also to a level of pain. From the temperature viewpoint, a subject is comfortable when he feels neither hot nor cold. When he is hot or cold, he can accommodate physiologically to his environment but still be uncomfortable. When acclimatization takes place, he is comfortable since he is no longer conscious of his accommodation. After he is exposed to the environment, permanent physiological changes take place which are defined as adaptation. Human response to altitude is parallel to the response to heat and cold. When a human, whose normal environment is sea level, is flown to 8000 ft, he must accommodate to this level by changes in respiration. He is conscious of an accommodative effort. (This is a common experience of air passengers from the East or West coasts when they debark for a stretch at Albuquerque.) Although he is not necessarily cyanotic, he has a sensation of air starvation when exercising. Passengers do not have a sense of comfort nor complete freedom from this sensation above 5000 ft until they are acclimatized. Normal healthy people can accommodate to altitudes as high as 12,000 ft. On the other, Haldane has observed cyanosis at altitudes as low as 8000 ft in normal subjects acclimatized to sea level.

During the recent war there has been a great deal of transocean flying by the Air Transport Command, the Naval Air Transport Service, and tactical aircraft at altitudes of from 8000 to 9000 ft without regular use of oxygen. At first, the same aircrews were used for the complete transoceanic run without change. Now crews are rotated every 8 to 10 hr at intermediate stops, and given 24 hr of rest before completing another leg. This rotation practice has resulted in a great improvement in pilot efficiency. After from 24 to 36 hr of from 8000 to 9000-ft flying with occasional stops, passengers often report extreme lassitude for several days on returning to their businesses.

Although at 8000 ft a pilot can act without handicap in an emergency, long exposure of from 8 to 12 hr leaves him, as a rule, sleepy, unable to concentrate, and with a general lack of motivation. In reality, the 8000-ft isobaric for pressure-cabin aircraft was proposed back in 1934 when flights longer than 4 hr were not contemplated as a routine. The experience of this war at flight levels of from 8000 to 9000 ft for from 8 to 12 hr has demonstrated that for pressure-cabin aircraft, comfort of passengers and efficiency of crews demands the use, wherever possible, of isobarics of 5000 ft or lower.

In summary, aviation is now long past the pioneering stage in which comfort of passengers and efficiency of crew were minor factors compared to performance and speed and altitude records. Aviation engineering has advanced so far that the price, in weight penalty and performance, for safety and comfort is small. This is especially true when it is realized that speeds of more than 300 mph and flight of from 8 to 12 hr are commonplace. Cabin pressurization is the first step taken by the aviation industry to include in the structural design of an aircraft a factor devoted entirely to the safety and efficiency of aircrew and the comfort of the passengers.

PART II

PSYCHOLOGICAL RESEARCH IN THE ARMY AIR FORCES

By

C. W. BRAY

PART II

PSYCHOLOGICAL RESEARCH IN THE ARMY AIR FORCES

SUMMARY

1. This report was prepared to indicate broadly "the relation of psychology to the development of AAF equipment in order to facilitate its use by the type of personnel likely to be selected and trained for its operation. Suggestions as to how the experimental and psychological data acquired during the present war may be best utilized as an aid to future planning are also to be considered."*

2. The following survey report reviews the wartime application of psychology to (a) fitting the machine to the man, and (b) fitting the man to the machine. The first is the problem of equipment design in terms of the human factor. The second includes three problems: (1) the development of optimum operating procedures, (2) the development of improved training methods and (3) the development of classification devices and procedures so that each man is appropriately allocated to the job for which he is best fitted. During the war each of these problems has been met and partially solved for specific jobs by psychological research.

The results of a number of successful specific studies on the above-mentioned problems are described in the report. Some of the illustrations are drawn from research on Air Forces problems. A number are drawn from other military activities. In general the examples illustrate the types of research which have proven fruitful and which might profitably be continued in the postwar period in order to improve the efficiency of the Air Forces.

3. The most general conclusion to be drawn from the survey is that psychological research can assist the Air Forces to considerable degree. Gains of 10-20% in operating efficiency and savings of the same order of magnitude in training time and facilities are indicated from research already completed. In peacetime, such research can be more adequately carried out and it is to be expected that somewhat greater gains can be obtained.

4. The report indicates that the psychological approaches to equipment problems are closely interrelated. Thus, if military devices are changed, operating procedures,

* Letter, 23 April 1945, Theodore von Karman, Director, AAF Scientific Advisory Group, to Irvin Stewart, Executive Secretary, OSRD, Attention W. S. Hunter, Chief, Applied Psychology Panel, NDRC.

training methods, and classification devices must be changed. Studies in any of the four fields use methods common to the others. In every instance the fundamental research problem is to obtain a measure of the efficiency of the man-machine combination. This measure permits comparison of the relative adequacy of alternative designs, of alternative operating procedures, of alternative training methods, and of alternative classification devices. The psychological approach to these problems, since the approach is through measurement, is thus not different in fundamentals from the approach of any other scientific or technical group to its own particular problems. The difference between psychology and the other sciences, insofar as this section of psychology is concerned, is that the psychologist has developed special techniques for the measurement of the human factor in the man-machine combination. It is concluded that future research should be carried out by a single, integrated psychological group, working as a part of a general scientific and technical research organization.

5. It is further indicated in the report that research can be most effective if it is carried out preliminary to the production period. During the preproduction phases time is available for research. Knowledge gained at this time has the widest application.

6. It is therefore recommended that a psychological research group be established in any scientific organization concerned with the development of new Air Forces' equipment in the postwar period. The psychological group should be charged with the duty of studying (a) the design of new equipment as affected by the human factor, (b) the development of optimum operating procedures, (c) the development of effective training methods and devices, and (d) the organization of classification tests and procedures which will permit assignment to training of men with special aptitude for operation of the new device.

INTRODUCTION

Research and development in the sciences and engineering led, during the war years 1939-1945, to mass production and mass use of equipment. The result was to strain the capacities of men to operate efficiently. Devices, which could readily be handled by personnel who had long been familiar with them, proved difficult for the inexperienced and for those trained by wartime methods. New devices were continually introduced. These added to the difficulty of smooth, efficient operation since they were hurriedly designed and since they were even more complex than their predecessors. Much of the advantage of the improvements and much of the value of large-scale production was wasted because the devices taxed the capacities of men.

In these circumstances two methods of seeking improved operating efficiency were possible and, in specific cases, were tried. The more fundamental approach was to improve the design of the equipment so that the machine fits the man. The second approach was to fit the man to the machine by development of improved operating procedures, training methods and classification devices. It is the purpose of this report to describe a number of instances in which the military psychologist provided the knowledge required for more satisfactory use of equipment through research and study of the man-machine combination. The examples cited provide a basis for a visualization of the possibilities in postwar research and for a description of the kind of organization under which such research will most likely be successful.

FITTING THE MACHINE TO THE MAN

THE DESIGN OF EQUIPMENT IN TERMS OF THE HUMAN FACTOR

It is not always a simple matter to determine the ways in which equipment might me modified to permit higher efficiency in operation. Observation of operation in the case of complex materiel is difficult. Sometimes, as for instance in the case of the tail or ball-turret gunner, it is almost impossible to observe the operations. Sometimes the fact that picked, trained men secure good results with a given device obscures the fact that the device is, at best, difficult to handle, and at worst, for the average man, impossible. When equipment is highly complex, results are affected by many factors, not only of materiel and personnel but of wind, weather, and other chance elements. Under these conditions it becomes very difficult to determine the remedies. In particular, the inability to record results systematically and with proper control of variable factors, prevents adequate development of military equipment.

Conversely the nature of the difficulties is often made clear by careful measurement. A case in point is the remote-control gunnery equipment of the B-29 airplane. The development of flexible gunnery led from the very simple open sight on a hand-held gun to more and more complex systems of gun control. In the B-29 sight it is necessary to track a target accurately and smoothly, in azimuth and in elevation, to frame it within a reticle of variable size and to trigger at appropriate moments. The complexity of the task was apparent to all but the causes of difficulty were not obvious. Opinions differed as to remedies. In this kind of situation recording the performance of the man and machine provides information which permits analysis of some of the difficulties (Refs. 1 and 2).

A pedestal and ring sight from a B-29 were set up so that gunners could track motion pictures of targets. The movements of each of the sight controls were translated to writing pens on a paper moving at constant speed. The pens thus provided a record of the azimuth and elevation controls, the framing control and the trigger. Since the motion of the target on the screen could be measured and synchronized with the moving paper it was possible to measure the accuracy of use of the various controls.

Some errors are so large that they are revealed by simple observation of the record. Thus, the errors in framing were always great in proportion to range in the early part of the attack. At this time the target is so small that even the thickness of the reticle dots deserves consideration as a partial contribution to range errors. The result also suggests consideration of magnification of the target image.

The records reveal that the controls are awkwardly placed. Each time that the trigger is depressed or released, tracking and framing are seriously disturbed. When the trigger is pressed (or released), oscillations of tracking of the order of 10 ₥ occur. Similar oscillations appear in records of framing. Since the guns are remotely situated, the cause of the oscillations cannot be the recoil of the gun. It is the movement of the thumb in triggering which disturbs tracking and framing.

Some disturbance of tracking with triggering is probably inevitable, but the amount of the effect is inordinately great in the B-29 sight. It could readily be reduced by redesign of the trigger. Tests of alternative trigger designs are now in progress to determine the best design and the actual gain to be expected from modification of the trigger. Some estimate of the latter is desirable in order to provide a sensible basis for decision as to whether a fairly expensive change is worth while. It is to be noted that advance study of the sight, before production, would have eliminated the necessity for modification.

Study of the records also shows that firing is independent of the accuracy with which the target is tracked and framed. Men press the trigger whether or not they are on target. Firing becomes a semiautomatic act of the gunner who appears to set up a rhythm peculiar to himself. Once he starts to fire he presses and releases the trigger in a fairly regular way which bears no relation to accuracy and none to the target course. Each man has his own rate. Some men fire many bullets, some few. These facts are true of B-17 and B-24 gunners whether or not they have had combat experience, of trained and partially trained B-29 gunners, and of officer and enlisted gunners. Results on the different kinds of gunners are tentative because of the small numbers studied to date and because no B-29 gunners returned from combat have been available for study. It is possible that trigger control would be more adequate if the gunner's problem were not so complex. Thus an automatic range unit, by eliminating the necessity for framing, might restore to the skilled gunner his ability to choose the best moment for firing.

Such results suggest several problems and possible solutions: (1) the training of gunners with respect to triggering might be changed; (2) gunners whose rates of fire are of such a character as to improve their chances of hitting might be specially selected and others rejected for this position; (3) accuracy would be improved if the trigger were redesigned and relocated so that its use caused less interference with tracking and framing. Errors due to triggering would be practically eliminated if, in addition, intermittent triggering by the gunner were unnecessary. Since tirggering does not occur at the right time it does no good (in terms of hits) to trigger intermittently. A trigger similar to an action switch could be provided which would permit either (a) continuous fire or (b) automatic burst control using a simple interval timer weighing a few pounds to control the duration of burst and rest intervals. The choice between continuous fire and automatic burst control, or the choice of the precise time intervals for automatic bursts, would clearly be a problem of materiel alone, although the mathematician might have something to say about optimum intervals.

Obviously the suggested changes in materiel or in operating procedure under (3) above are fundamental solutions while the suggested changes in personnel under (1) and (2) above are expedients. Continuous fire or automatic burst control would simplify an awkward, complex task and thus would reduce rather than increase the already great demands for training time and more stringent selection.

The problem of controls for the B-29 gunsight is being studied more generally than for triggering alone. Observation of gunners at the sight reveals that the controls violate certain basic principles of movement. Thus the framing and elevation controls are interlinked so that, for the same rate of range change, the gunner must frame at different rates, depending on the direction of the target's movements in elevation. It is clearly desirable to modify the sight so that the same target changes can be matched by the gunner with the same changes of the sight controls.

An analysis of the sight reveals a number of violations of basic principles of body movement. Modifications of the controls, in accord with psychological principles, have been constructed and under trial. It is possible that experimental evaluation of the engineering applications of these principles will require further modification. Ultimately the psychological principles themselves should be tested on the basis of experiment and reformulated in engineering terms.

A second study in the design of equipment also illustrates the nature of the psychological approach and brings out an interesting conclusion on the relation of man to machine. The Field Artillery observed that 100 ₥ errors in fire occur too frequently, sometimes with too much effect on our own troops. The error was a "human" error and psychologists were asked to help correct it.

The first step in research was to determine the number of errors that occur. In actual fire by fairly well-trained troops on practice maneuvers, without the pressure and emotion of combat, a 100 ₥ error is fired about once in a thousand rounds. Many more errors are made but most are corrected before firing. Every error causes a loss of time. In dry runs experienced gunners have been observed to make as many as 6-7% of readings and settings in error. About half the errors are 100 ₥ (or multiples of 100 ₥).

Why should errors of 100 ₥ be more or less frequent than errors of 10 ₥, or errors of 1 ₥, or errors of any given amount? Even casual observation of the sights in use indicates that the design of the scales predisposes to 100 ₥ errors. Field Artillery sights have a gross and a fine scale. The first scale reads in hundreds and thousands while the second reads in tens and units. An error of one scale unit on the gross scale gives a 100 ₥ error. The gunner's problem is unnecessarily complicated by the fact that the fine scale is separated from and located to the *left* of the gross scale so that normal habits of reading numbers are violated. When called upon to carry out mental arithmetic in four-place numbers (0-3200 ₥) the complication becomes serious and errors in setting occur.

This is by no means the sole source of error, even of the 100 ₥ error. Studies show significant differences in the number of errors that occur in comparative test runs (dry runs) using a modern Field Artillery sight, an older Field Artillery sight, and a modern, captured, German sight. Results are illustrated in Fig. 1. Although the German sight was relatively unfamiliar to our men, only 61% as many errors occurred on it as on the modern American sight. The older American sight turned out actually to be superior to the modern, giving only 80% as many errors. The chief advantage of the German sight appears to be in the finer and more permanent scale engravings and the generally cleaner appearance of the sight.

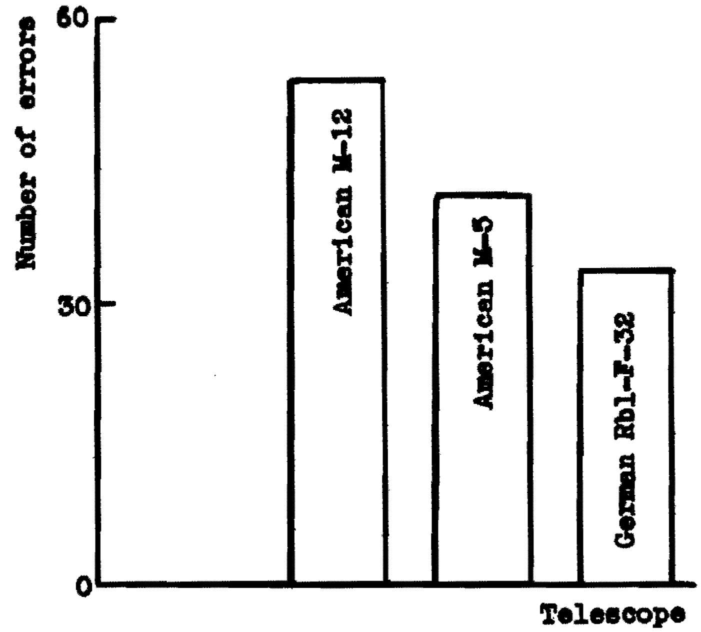


Figure 1 — Errors in Setting Deflection on Three Different Panoramic Telescopes During 1700 Trials Each.

Further study of the nature of the errors on these sights gives an interesting conclusion. The errors are human errors in the sense that they can be eliminated or radically reduced by special selection or by special training of personnel. Experienced gunners and men with high AGCT (intelligence test) scores make few errors. On the other hand, 90% of all errors can be traced to the design of the equipment in the sense that a particular type of error appears in one design and not in others, or in the sense of obvious relation between type of error and design (Ref. 4). New sight designs, better adapted to the limitations of the men who will use them, have been developed for trial.

The equipment, therefore, opens the way for human error. We may ask: What proportion of airplane crashes now blamed on pilot error could be eliminated by designing the equipment in terms of the user rather than in terms of engineering economy and simplicity alone? How much need for special training and for selection could be reduced in the same way? The answers to questions of this type could only be given if further research were successfully completed. The basic methods for such research on the pilot are now available. The efficiency of a pilot is routinely measured in the experimental work on training and classification carried on by psychologists of the Air Surgeon's office and the Committee on Selection and Training of Aircraft Pilots of the National Research Council. Efficiency is measured by photography of a remote instrument panel containing the standard flight instruments and certain specially designed devices as well. The methods used in studying training and classification (Ref. 5) could be applied to the study of the comparative merits of various cockpit designs.

Research in the fields described above is closely related to the problems of testing new equipment. New devices are generally submitted to comparative trials in which their efficiency is compared directly with existing equipment or to knowledge of efficiency of the existing device gained in previous tests. Until recently such tests were usually carried out without knowledge of the possible influence of the presonnel factor. Thus, factory engineers or materiel officers ran the equipment in many tests. Their results are not comparable to those obtained with typical service personnel. In other cases, results of use of equipment by officers were compared with results of use by enlisted men. In one instance psychologists were permitted to observe a comparison of two gunsights, a new sight operated by one man, an old sight operated by another. After a few runs it was clear that better results were being obtained with the new sight. The tests were then called off and preparations were made to accept the new device. It required some urging to secure a continuation of the tests with reversal of the positions of the men, but when this was done the apparent merits of the two devices were reversed. The old model was now the better. Such an extreme case of poor control of the personnel factor in tests of equipment is fortunately not typical. Nevertheless the control of the personnel factor is frequently inadequate.

The solution of the problem of control of the personnel factor in tests of equipment is not simple, even though it is necessary if tests are to give meaningful results. For instance, three groups of Army personnel have shown, by measurement, an accuracy of ranging when using the B-29 sight of the order of about 20, 15, and 12% of range, respectively. Each group was supposed to have been trained in operation. Obviously if one device is operated by personnel from one of the above groups while another is operated by personnel from another group, the results will be predetermined by the personnel unless the devices differ greatly. The simple solution of using the same personnel on each device is not always practicable and may introduce other psychological problems, as for instance: (1) Men tend to prefer the device with which they are more familiar. (2) Previous use of a given device makes it easier to operate a related, similar device under some conditions, but may make it harder to operate under other conditions. Experience in equipment testing is not yet adequate to lay down all the general principles which should govern such tests. Until additional general principles are discovered the wisdom of capable research personnel must be consulted as to whether or not the tests are adequate.

The three applications of psychological method to design of gunsight controls, Field Artillery sight scales, and tests of equipment are illustrative of a series of such studies now completed or in progress. Studies include the optimum sensitivity of radar scopes (millimeter of motion of blip on the scope facer per mil of target motion); the best design of reticle in various kinds of gunsight; the comparison of direct tracking, rate tracking and aided tracking in computing sights and directors (including various values of constants in rate tracking and aided tracking); the best type of communication equipment, etc.

There should also be some mention of the nonexperimental contributions made by those interested in the human factor; provision of platforms of variable height so that men required to stand in operating position for long hours will not also be required to stand on tiptoe or to bend over; provision of body supports, so built that the men will be comfortable but also so that their body movements will not be communicated to the device; adjustment of balance of heavy gear; etc. (Ref. 6). Such changes are not, properly speaking, of an experimental character. Nevertheless it is clear that men interested in the human factor and working on equipment design will be more likely to see possibilities of improvement of this kind than will men whose interest is solely in simple engineering design. Men interested in the human factor will inevitably be able to suggest minor and inexpensive changes which will add to the efficiency or to the comfort of the operator.

FITTING THE MAN TO THE MACHINE

OPERATING PROCEDURES

Problems of the best design of equipment are closely related to problems of the best operating procedures. Complex procedures can often be replaced by simple procedures if minor changes of equipment are made. The best equipment makes operation as simple as possible. On the other hand even the best design can be used in a number of ways, some efficient, some less so. Determination of optimum operating procedure has usually been a matter of slow accumulation of experience. Occasionally it has been subjected to the semipsychological time and motion study. For many problems, experience is too slow and time and motion study inadequate; and too often, decisions are made without experience or any type of study at all. In wartime such uninformed guesses are necessary. Haste would not be required during peace; orderly research is then possible.

The development of radar provided the possibility of a new signalling system. Code signals can be reproduced on a radar scope. Assuming that these signals may best be tied in to other communications if they take the form of Morse code, a number of questions are raised: What rate of sending will permit the average radar operator to follow accurately after a reasonable course of training? If less than the whole alphabet is required, what letters will be least likely to be confused with each other? These and other similar questions can be answered by experiment in advance of field experience and before decisions are made which later turn out to require use of an inefficient procedure.

The limit of the rate of sending is imposed by the human eye. When a light is flashed on and off slowly the eye can distinguish the signal from the background. If the light is flashed too rapidly the eye fails to follow the change; the light appears to shine steadily. Between the slow and the rapid rates the sensation of flicker appears. The light goes on and off but appears to vary in brightness. The sensation is distinctly unpleasant and even, in some cases, nauseating; flicker is to be avoided. In addition, the optimal relative duration of dots and dashes and of the intervals between must be determined so that the average operator can attain maximum speed and minimum confusion of dot and dash. If a dot is too short it cannot be seen at all. If too long, it is confused with a dash or, if the dash is also made longer, the rate of receiving is reduced with no gain in accuracy.

The different letters of Morse code are known to differ in difficulty when used in radio. Similar differences appear in visual code but, because of the differences between eye and ear, certain changes in the order of difficulty occur. The list below shows the relative frequency of error in visual reception of the letters shown. The data were obtained after training 26 Navy search radar operators to an over-all level of 75% accuracy in receiving code in the scope. These operators were of average ability in learning to receive code (Ref. 7). Unfortunately time did not permit a determination of the effects of various kinds of grass on speed of transmission or difficulty of letters. Nevertheless the results permit more sensible choice of a few relatively easy letters for identification symbols and similar purposes.

Letter	Percent of Errors in Reception
r	42
k	37
l	37
w	35
c	31
x	29
p	28
f	24
u	23
d	21
a	19
o	15
g	12
m	12
n	12
Average	25

Similar problems occur in voice communication over radio or intercommunication system. How loudly should a person speak? Doctrine varied. Based on the (false) analogy of commercial broadcasting, men in some units were instructed to speak at less than conversational loudness. In other units men were told to shout. The facts on optimal loudness over present Air Forces' intercom systems are shown in Fig. 2. The method of intelligibility testing was used for the study. That is to say,

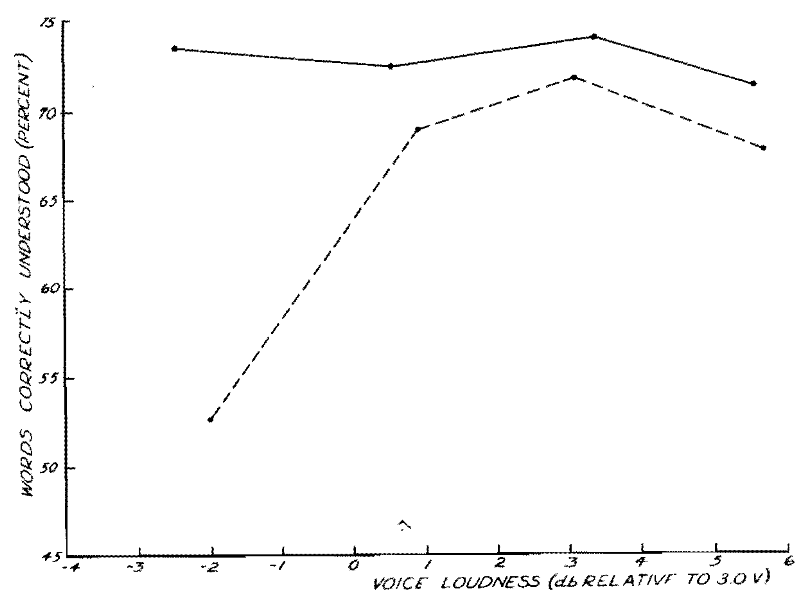


Figure 2 — The Effect of Voice Loudness on Word Intelligibility with Two Microphones Used in Simulated Airplane Noise at Ground Levels.

a number of students at a basic school spoke, in turn, a list of words into a microphone leading to 20 headsets. At each headset was a fellow student who listened and tried to write down the words he heard. Simulated airplane noise filled the room. The loudness of the speakers' voices was intentionally varied from weak to shouting. Appropriate instruments recorded the loudness of voice. The figure shows the percentage of words spoken at each loudness that were understood correctly. Two curves are shown; one is for the T-17-B hand-held microphone and the other is for the ANB-M-C1 mask microphone.

It is seen that with the older T-17-B microphone intelligibility is relatively poor with the weaker voice. It improves but decreases again as loudness is raised to very high levels. The facts were made clearer for training purposes when the optimum point on the curve was labelled as a voice that is just not shouting (Ref. 8). Other facts suggest that this same level should be used with the ANB-M-C1 when at altitude, although, as the figure shows, this superior equipment requires no special effort at ground levels. Similar data are available on the intelligibility of various methods of holding the telephone, on various message forms, and on methods of call-up. In each case there are considerable differences between alternative methods. Results are now incorporated in doctrine and in a training course.

What method of use of an open sight on antiaircraft machine guns will give the best results? In 1945, after six years of war, the question started heated arguments. A partial answer based on facts may be furnished by an experimental program of a project now working with the Antiaircraft Artillery Board. Because of the limitation on personnel and equipment forced by the war the answer will be far from final. Nevertheless the program should substitute facts for heated argument.

The development of optimum operating procedures for military equipment is thus shown to be a subject amenable to experimental research. Furthermore, in this field as in the design of equipment, research personnel with an interest in the human factor are frequently able to make immediate, nonexperimental contributions based on common sense, experience, and the general principles of psychology. Numerous examples might be cited from the activities of the war. The field is one which should prove fruitful in the postwar period.

TRAINING

With the development of adequate methods of measuring human proficiency it becomes possible to experiment with training itself. It is no longer necessary to answer such questions as the following on a basis of opinion: What is the best of a number of possible training methods? For how long should men be trained? Is a particular training aid useful or is its production and use a waste of time and money? The questions can be answered by experiment.

Figure 3 shows the result of an experiment comparing three methods of training antiaircraft gunners (director trackers). The three lines represent the accuracy of tracking of each of three groups, trained by different methods. As training progresses all the curves fall. The time off target (by more than 2 mils) is decreasing. All methods are successful in improving performance but use of a particular check-sight in a particular way gives the greatest improvement. Standard Army training gives the least improvement (Ref. 9).

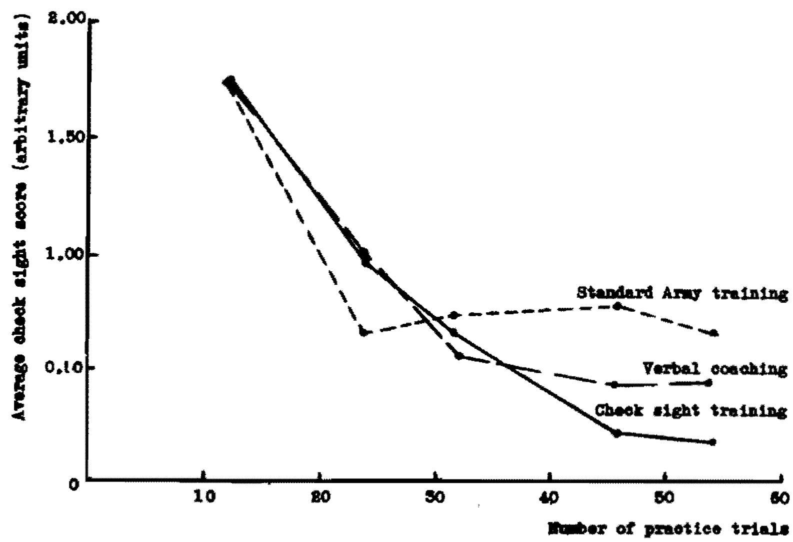


Figure 3 — The Accuracy of Antiaircraft Tracking Varies According to the Method of Training Used.

How long should a particular phase of training last? The average improvement in the accuracy of reading the scale of a PPI scope on a search radar trainer is shown in Fig. 4. Accuracy increases as training progresses, at first rapidly and then slowly. It is clear that not much improvement will take place after the eighth day. Therefore, training on this device need not continue long after that day (Ref. 10).

How many hours should be spent in radio code practice each day? The speed of code reception of two groups of student radio operators after five weeks of training is compared in Fig. 5. The figure shows the percentage of men from each group capable of receiving at a given speed. The two groups are much the same in performance. Yet one received four hours per day in training to receive code and the other received seven hours of such training per day. It is evident that three hours per day were wasted on the seven-hour group. The four-hour group was free for a considerable part of each day for training in related duties (Ref. 11).

Does a given training aid really assist the men to learn? In the case of one range-estimation trainer, research indicated that the men learned to estimate range by cues that do not exist on the firing line. The trainer permitted the men to use stereo vision, and other "secondary" visual effects in making the judgment. As a result target size was hardly used at all and successful training was not given. The observations paved the way for modification of the trainers to make it useful (Ref. 12).

The greatest gains from studies of training are demonstrated, of course, when an adequate training course is developed where no formal training of any kind was previously given. Despite the emphasis on the need for training in the Army Air Forces, important duties are sometimes not taught except by chance experience. Voice communication by telephone and voice radio is at the heart of modern warfare. Nevertheless, no formal training in use of the telephone was given prior to 1944.

Development of a short, formal course (four hours) for air personnel gave relatively large gains (Fig. 6). Before training, a number of student pilots at a basic

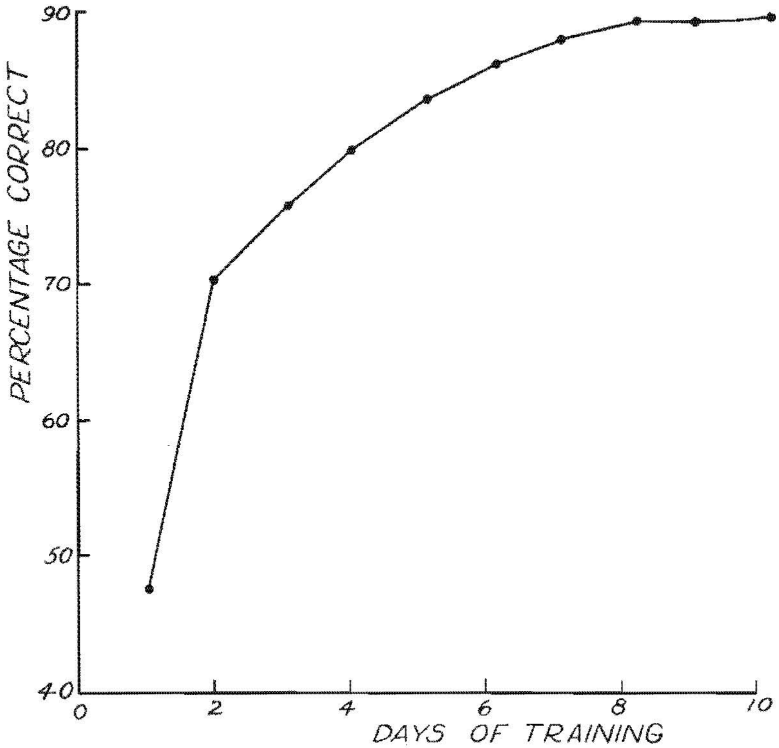


Figure 4 — The accuracy of reading blips on a PPI trainer improves up to about the eighth day of training. Further training on this synthetic device would be of little value.

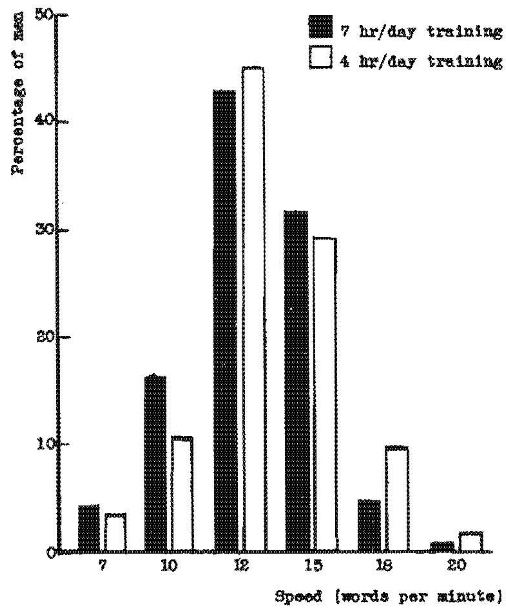


Figure 5 — Each bar represents the percentage of student radio code operators able to receive code at a given speed after 5 weeks of training. One group was trained 4 hours per day and the other 7 hours per day in reception. There are no differences.

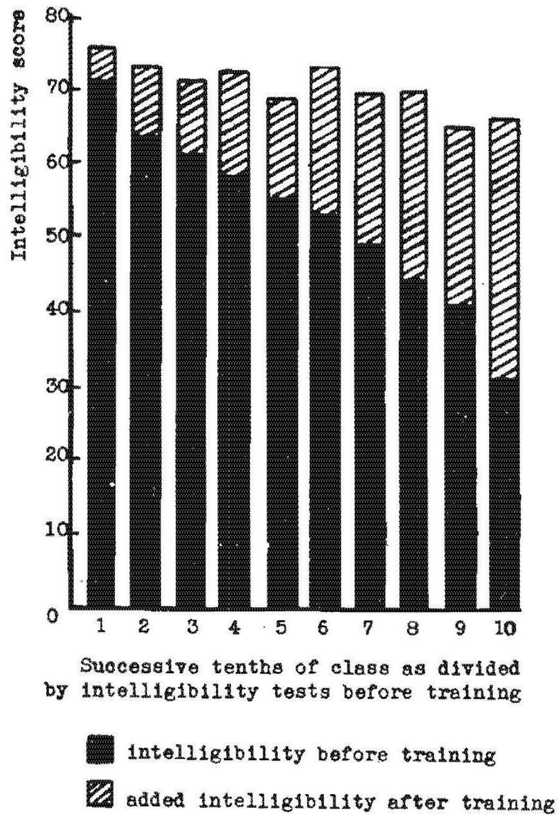


Figure 6 — Effect of Training on Intelligibility Over Radio and Interphone in Airplane Noise.

school were evaluated by the method of intelligibility testing described above. The percentage of words correctly understood by the listeners for an average group of speakers is shown in the figure. The percentage of words understood before training is shown by the solid portions of the bars. After the four-hour training course, which incorporated some of the optimum operating procedures described above, the same student pilots spoke a list of words of equal difficulty over the same system and to the same "jury" of listeners. The shaded additions to the bars represent the results. The men were ranked for intelligibility before training. The top bar shows the effect of training on the best tenth of the class and each succeeding bar shows the improvement of succeeding tenths of the class. Improvement is slight for the best men and becomes greater for those who originally were less clear in their speech.

The necessity for giving special training in voice communication was shown by a study related to that just described. Flight instructors and combat experienced air crewmen who had not had the special course were no more intelligible than untrained cadets. Four hours of training increased their intelligibility as much as it did for the cadets used in the study summarized in Fig. 6 (Ref. 13). The results are so clear that the office of the Chief Signal Officer wrote: (The research) "developed training methods by means of which intelligibility over the interphone and radio telephone may be increased on the average as much as 25% . . . an average increase of 25% in intelligibility is greater than the increase that has been obtained in recent months through costly changes in equipment."

These and other studies suggest that an estimated 10-20% could be added to operating efficiency in any skill of importance by paying attention to approximately half a dozen basic principles of training. Development of methods of application of the principles to specific kinds of training is a major task for the postwar period. The principles are:

1. Analyze the job carefully and completely, listing what is done, how it is done, and why it is done. It is surprising to find that many instructors do not know the elements of the job, their relative importance, or the difficulty of learning each part. A job analysis solves this problem in part and permits sensible planning.

2. Organize the material to be learned in simple, logical form. Present the objective and the methods of reaching the objective in terms which the student can understand. Give the simpler material first, the complex later. This applies to skills as well as to verbal principles.

3. Present the material to be learned in a variety of ways. Use visual aids, audio aids, movies and models.

4. Provide opportunity for supervised practice. Skills are not taught by words, nor are they adequately taught by merely running the man through the job time after time. The best trainers provide automatic supervision by means of a signal telling the student when he is right or wrong.

5. Measure performance. This motivates the men to competition, including self-competition. It provides the basis for coaching, including self-coaching. It permits standardization of graduation requirements, and hence of operating procedures. It provides superiors with the basis for quality control and improvement of methods.

6. Praise whenever reasonable. Let criticism be rare. Be sure that either praise or blame relates to a specific action.

7. Select and train the instructors themselves. Not every man who can operate a gadget well knows how he does it. Even when he does there is no assurance that he can teach others.

CLASSIFICATION

A major contribution of psychology in this war has been in the application of tests and procedures developed in the prewar period and during the war itself to efficient use of man power. Possibly the most successful work in this field has been the development by psychologists in the Air Surgeon's office of a battery of tests for classification of pilots, bombardiers, and navigators. A number of tests are given to each cadet who has passed qualifying examinations. Each cadet takes the same tests. Three scores are derived from the whole series of tests. These scores predict with very considerable precision the probable success or failure of the cadet if he is trained as pilot, bombardier, or navigator. The percentage of failure among cadets who received various scores on the tests and were then sent through pilot training is shown in Fig. 7. The percentage of washouts among those scoring best on the test is less than 5%. It is more than 75% among those scoring worst on the test. Results to date for navigators are more impressive, for bombardiers they are less so (Ref. 14). The success of this battery led to its adoption by the RAF.

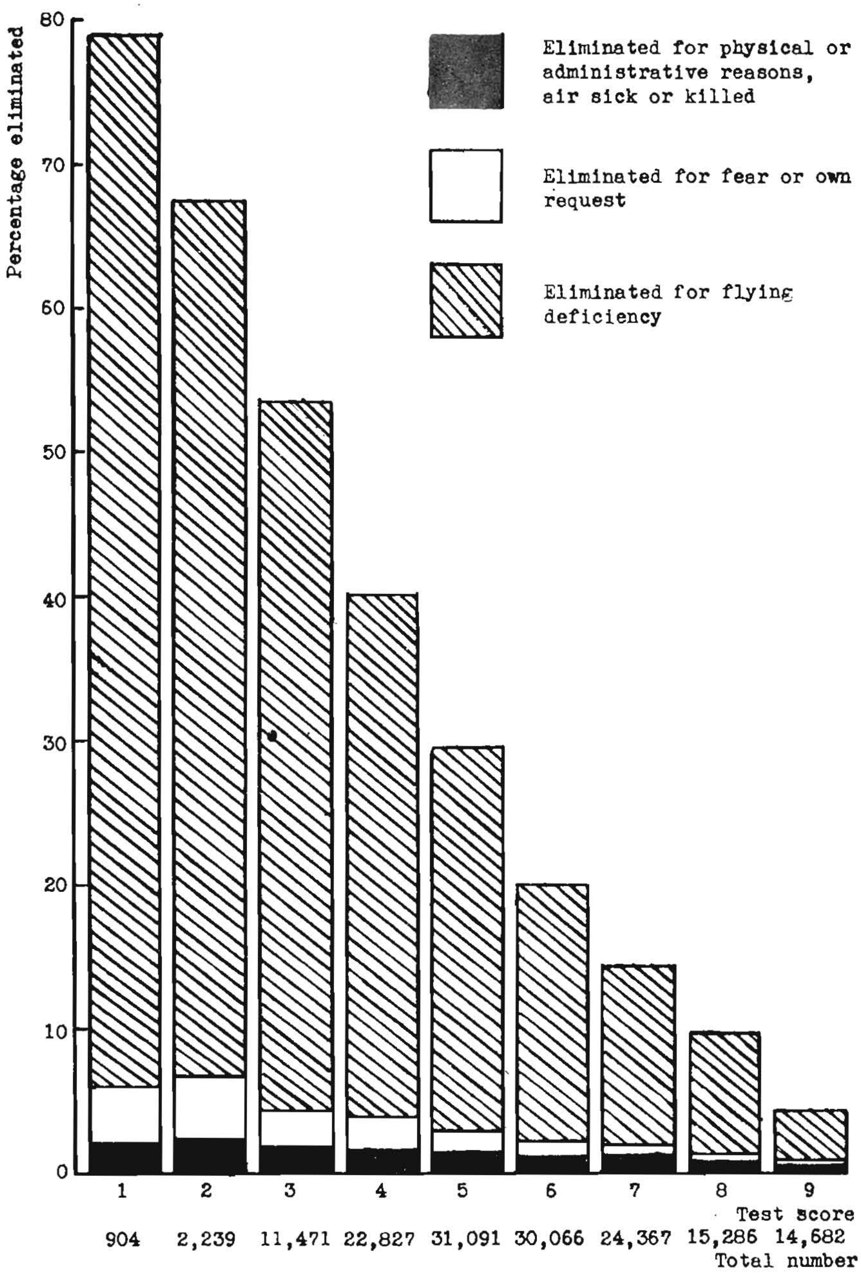


Figure 7 — Prediction of Success in Pilot Training from Aptitude Tests. Each bar shows the percentage of men with a given score on the AAF Basic Classification Battery (scored for pilots) who washed out in primary pilot training.

Some agencies have tried to use biographical information (education, sports, occupations, hobbies, etc.) to supplement test scores in assignment and classification. Biographical information has one major advantage over test scores. It covers a wider range of information in a short time. But its disadvantages outweigh the one advantage. The information is qualitative instead of quantitative and is therefore harder to use in standardized forms and procedures. The young men most preferred for for military service have had small opportunity for the varied experience which would be valuable as a basis for classification. Because of these disadvantages of biographical data, aptitude tests are likely to remain as the principal basis for classification. The best system will make it possible to supplement test data with whatever other accurate information is available.

The development of military aptitude tests is still relatively new. Much remains to be done if the Army is to enter the next war with a system which will then be adequate. In 1939 when psychologists offered their services to the Office of Adjutant General in relation to classification they were told that the Army had its system all prepared. When they asked the nature of the system they were told that the Army Alpha intelligence test developed in 1917 was its foundation. When they asked who would supervise the administration of the system they were told that psychologist reserve officers would do so. The entire Army and Reserves contained fewer than a score of qualified psychologists, and the system which was contemplated was a primitive and outdated as the airplanes of the war of 1914-1918. In consequence, several years were lost while a new military system was devised. A similar failure to develop with the times will be inevitable after this war unless research is continued.

Three major problems in the field of classification can now be foreseen for continued study by the Army. The first is not a research problem but it is one in which the research man can advise and assist. It is to secure the successful use of knowledge available. Classification tests are available now for many Army occupations. More are being constructed and evaluated though the war is over. However, only a small fraction have been actually realized. Only in the classification of aviation cadets in Army and Navy has psychological data been adequately used. Elsewhere classification is sporadic and uncertain in its effects. In many cases basic data are ignored in original classification. In many cases when original classification is properly made, transfers occur arbitrarily and for minor reasons. When transfers occur as a result of major changes of plan, as when large numbers of infantrymen are suddenly needed, the situation is understandable and reasonable. When it results from lack of an adequate administrative system the failure can only be ascribed to the inevitable, widespread ignorance of the possibilities in a relatively new field. The Army has devoted an immense amount of time and energy to the development of a supply system which attempts to deliver the right supplies to the right place at the right time. A similar effort should be made for manpower.

A second problem necessitates further research, though some of this can only be carried out under war conditions. This is to study the usefulness of different classification procedures in the prediction of skill in combat. A great many tests have been proven to be useful in predicting success in Army schools. This type of prediction is important, for successful completion of special school programs is a necessary step on the road to combat. But it is even more desirable to predict combat performance accurately. If improvement in ability to predict combat performance is to come about, it is necessary to try out and evaluate various prediction methods.

Tests which are developed merely to predict school success will not do the best possible job in predicting combat skill. Tests which are developed to predict measured skill, even though the skill is measured during practice rather than in combat, will do a better job. Direct research at or close to the combat zone is required to develop classification to the point at which it is aimed: the improvement of combat efficiency. To the knowledge of the writer not enough effort is now being expended in this direction. Only in the cases of Army and Navy officers and in the case of a few Navy surface ratings was there active research in progress and even in these the number of research personnel engaged was quite small. Such research is, though, impossible in time of peace.

The third problem in this area is to work out the needs of the various Service branches for men of various levels of general ability. Personnel procedures are still being operated according to principles of selection rather than of classification. Certain branches, varying perhaps with the priority of the job, perhaps with the insight of their leaders, and perhaps with their willingness to employ psychologists, have successfully competed with other branches for the generally good men. Time and again research reports have shown that certain general abilities make for success in almost any line. Thus pilots, rangefinder operators and underwater sound operators do a better job if they stand high on tests of verbal aptitude, mechanical aptitude and elementary mathematics. A common relation of this sort reflects, in part, faulty training. Ability to use and understand words, for instance, probably should be relatively unimportant in the lower levels of all three jobs. As long as training is highly verbal, then so long will a verbal test predict ability. Verbal aptitude should probably be a requirement only for the higher levels of military jobs where communication with others is basic to success.

Pilots, rangefinder operators and sound operators not only benefit from possession of high general ability, but they have need for special abilities as well. Thus, pilots need good psychomotor coordination. Rangefinder operators need good stereoscopic vision. Sound operators need ears that can distinguish sounds differing only slightly in pitch, timbre, and time characteristics. Tests for these special abilities have been developed and proven useful.

It follows that it is possible to develop a sensible program for use fo manpower. Men of high general ability are needed in every branch. They furnish the leaders, the brains. They provide a sound basis of growth and development, a basis for dealings with other branches, and for higher command. Not every man with general ability will turn into a great leader, but no branch can succeed if the average officer, commissioned or noncommissioned, is of generally low intelligence or lacks mathematical or mechanical ability. A good army must be well balanced in this respect; since its future is unknown it must be prepared in all lines. The personnel problem then, is a problem not of selection of the best for a few jobs but of classification of all. Manpower must be allocated into the slots which best suit each man. Fortunately the existence of specific tests of proven value indicates the possibility that this can be done. It can be done now for a few jobs. The splendid achievement of the Air Forces in working out separate, relatively noncompetitive tests for pilot, bombardier, and navigator indicates what might be done for all personnel if appropriate research were completed. Savings of 10-25% in total training time for all men can now be produced by appropriate use of tests. Efficiency of operation, where it has been studied, is known to be similarly improved.

NEW EQUIPMENT

In studying the design of equipment and in developing operating procedures the research psychologist must work hand in hand with the designer and vice versa. Nor can the designer afford to neglect the fields of training and classification. If a new device is to be used successfully men must be trained to operate it and the device must be so built that it can be operated by the men who are likely to be assigned to it. The designer has already begun to pay attention to training. Training aids are now occasionally built by the same groups who produce new equipment. In general, however, such an interest has been shown only for a few lines of development.

In this connection it seems obvious that the time to carry on research, not only in equipment design and operating procedures but also in training and classification as well, is before production of a device begins. After production has begun, training and personnel agencies are swamped by the mechanics of handling masses of men without adequate training materiel and without an adequate understanding of the nature, purpose, or use of the new device. The development of training and classification methods takes just as much time as the development of the device itself. This time is available only during the design and preproduction phases.

The development of suggestions for training and classification is not, of course, the function of the physicist or engineer. It is properly the duty of training and personnel specialists. Nevertheless no one is in a better position to guide and assist the specialist in training or classification than the designer. No one has a better reason to do so.

What is needed is a liaison group, understanding the human problems and interested in solving them by whatever means are available, whether by modification of equipment, by simplified operating procedures, by improved training, or by better classification.

With these considerations in mind the Navy and the Applied Psychology Panel, NDRC, set up a Project N-111, Psychological Problems in the Operation of Antiaircraft Lead-Computing Sights and Directors. Headquarters were established at a materiel center and school for maintenance men, the Washington Navy Yard. Effective and continued advice is given by operating, materiel, and personnel bureaus of the Navy. The project is staffed by capable civilian psychologists, including some with a firm background in mechanical engineering, electronics, or mathematics. Cooperation of manufacturers is obtained. At least one preproduction model of each of the

Directors, Mk. 51, 52, 57, 63, 56, 60 and 61 has been or will be delivered to the project for study. The project, with active Navy assistance, trains men in various methods of operation, being prepared to compare the different methods by formal experiment if this seems desirable. Standard operating instructions are worked out and a few crews are trained in accordance therewith, so that field trials of additional preproduction models may be made by crews of reasonably well-trained men. Following this experience and following field trials, a pamphlet of operating instructions and suggestions for selection and training of crews is prepared by the project and distributed by Cominch with each production item.

The project is in an excellent position to note and suggest correction of design factors which make operation difficult. Some corrections are simple and obvious, as when a model appeared which could be operated only by men who are six feet tall and not even by six-footers on a rolling platform. Others are less obvious and require at least a quick try-out as, for example, the need for a counterbalance, the requirement for shoulder straps, or the possibility of a built-in checksight for training purposes. Still others require definite and complete experimentation as, for instance, the best design of reticle. Studies of synthetic trainers, suggestions for training procedures and for classification complete the agenda of work.

One judgment of the usefulness of the project staff is that of its chief Naval Liaison Officer who, after six months of work by the project said, "I feel that they will advance the Navy at least 12 months over previous procedures in handling new directors."

The success of this project is worth analysis. It reflects at least the following:

1. Existence of a real need for psychological study of new equipment.

2. Careful organization to insure that the research is done in the most effective time and place.

3. The calibre of assistance and the amount of time devoted by Naval officers. This includes assistance in securing research facilities, diversion to the project of at least one preproduction model of each new device, participation in the work itself and, particularly, active steps to insure application of results.

4. The education in technical subjects and the psychological caliber of the project staff.

5. The "know how" of the research group resulting from prior experience in military research.

These characteristics of the organization of Project N-111 should be seriously considered in any postwar program. Unless there is a real need, unless the research is done at the right time and place, unless the Services are prepared to try to understand, to give active assistance and to trouble themselves to apply results, and unless the research personnel and their representatives at higher echelons are professionally capable, much is wasted that might be gained from a research program.

There can be little doubt of the existence of the need. No army can afford to allow the skill of its personnel and its knowledge of how to produce maximum operating efficiency to decline. Even small gains and losses, of the order of a few per cent, can be of consequence in such an integrated structure as a modern army.

POSTWAR PSYCHOLOGICAL RESEARCH IN THE ARMY AIR FORCES

In the light of the wartime record, the value of psychological research to the Army Air Forces is proven. This is not to say that all such research has been valuable and successful. The failures have not been recorded in this survey. The causes of failures have, for the most part, been the lack of some one of the conditions of the success of Project N-111 outlined above. When there is a need, when work is done at the right time and place, when service assistance is capable and active, when the research staff is qualified and experienced in military research, failures are rare.

There is one additional condition of successful research which has been noted by psychologists in and out of the Services. Psychological research groups should be responsible primarily to a single agency for scientific research. Their interests in such an agency should be represented by psychologists. If psychologists are scattered through the Services, or if they are attached, a few at a time, to this, that, and the other administrative, scientific, engineering, or medical unit, they soon lose their professional status as psychologists and much of their specific contribution is lost. This is not to say that there should not be close and continuous cooperation between psychologists and such groups. Nor does it prevent such groups from hiring psychologists as technicians just as psychologists hire engineers, mathematicians, and physiologists as technicians. It is, however, to point out that psychology is a subject in its own right and that subject may best continue to develop and to assist the Services if it is left primarily in the hands of those who know it best.

It is therefore recommended that a psychological research group be established in a more general scientific group setup to carry on postwar research and development work for Army Air Forces. Such a group might be established in a general scientific research corps if such were to be established, or in a civilian research agency such as the Research Board for National Security. Either type of organization seems fitted to attract and hold capable research personnel. It is to be remembered, however, that the purpose of postwar military research is only partly to carry on sound experimental work. It has also the purpose of educating as many scientists in military problems as possible. Only a civilian organization can obtain a reasonable number of professional men.

In such a general organization the psychological section would carry on studies of (1) the design of new equipment in terms of personnel needs, (2) operating procedures, (3) training methods and devices, and (4) classification.

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