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TRANSLATION

CONTEMPORARY MEANS FOR EMERGENCY ABANDONMENT OF AIRCRAFT (SELECTED CHAPTERS)

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

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CONTEMPORARY MEANS FOR EMERGENCY ABANDONMENT OF AIRCRAFT (SELECTED CHAPTERS)

BY: S. M. Alekseyev, Ya. V. Balkind, et al.

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TABLE OF CONTENTS

Chapter 1

GENERAL DATA ON CONTEMPORARY FACILITIES FOR THE RESCUE OF AN AIRCRAFT CREW UNDER EMERGENCY CONDITIONS

§1. FACTORS LEADING TO THE DESIGN OF AN EJECTION SEAT

An improvement in the tactical flight characteristics of flying craft is frequently limited by the physiological potentials of man. The contradiction between the required tactical flight characteristics and the capabilities of a human being became particularly pronounced in the recent decade, starting at about the end of the Second World War (1941-1945). As this contradiction was being resolved, there arose a new branch of physiology – aviation medicine* – and there were also new branches in aviation engineering, i.e., high-altitude equipment intended to ensure the safety and functional capacity of a crew during flight (oxygen masks, pressure suits), and rescue equipment intended to enable a crew to abandon an aircraft safety under emergency conditions; the first such piece of equipment was the so-called ejection seat.

It was only comparatively recently that the only available means for a member of a crew to depart an aircraft under emergency conditions was the parachute strapped to his back. In the case of an emergency the pilot (or any other member of the crew) abandoned his aircraft through the simple expedient of climbing out of the cabin. Having spent a few moments in free flight, he opened his parachute and descended safely to earth.

With the increasing velocities of flight, however, this method of safeguarding a crew in the case of an aircraft accident proved to be impossible for two reasons, i.e., at indicated velocities in excess of 400 km/hr it is, first of all, extremely difficult to overcome the very high airstream pressure encountered on leaving the aircraft and, secondly, at these velocities the stream would propel the individual abandoning the aircraft (if he were able to leave the aircraft in the first place) with such force that a collision against the wing, the horizontal stabilizers, or the fin of the aircraft would be totally unavoidable.

These conditions led to the development of an ejection seat, i.e., a seat equipped with a special firing mechanism which (generally by means of an explosive cartridge) imparts a vertical velocity to the seat, sufficient to pass up and over the rudder. Since this velocity must be imparted to the seat over a comparatively short path, the ejected seat and the human being are subject to considerable vertical acceleration.

As soon as the seat enters the airstream the man is subjected to G forces from back to front (the so-called deceleration force) and he is also subject to the pressure of the approaching free stream which causes the seat to turn, thus changing the direction of the acceleration.

Thus upon separating from an aircraft in his escape equipment a man is successively subjected to G forces in the directions "head-pelvis," "back-chest," "pelvis-head," and he is also subjected to the pressure of the approaching free stream, the effect of the angular velocity of seat rotation, and the dynamic shocks produced by parachute opening. He subsequently experiences a lengthy (if the escape from the aircraft occurred at great altitude) and rapid descent during which atmospheric pressure increases rapidly, and he subsequently executes a slow descent by means of the main parachute, finally landing on the ground (or in water).

The human organism is not built to withstand all of these pressures; therefore the individuals engaged in the design of escape and high-altitude equipment seek to attenuate the effect of these pressures to limits of human tolerance.

The problem is itself complex and made even more difficult by the fact that in addition to enabling an individual to escape from an aircraft under emergency conditions, the equipment must also provide for satisfactory performance in its primary function, i.e., the seat and equipment used by a pilot must provide the required ease and convenience of aircraft control. The requirements imposed on the equipment with respect to convenience of aircraft control and safety under the emergency conditions in which a pilot might be called upon to escape from his aircraft are contradictory. If in addition we consider the difficulties of testing this type of equipment under actual conditions (tests with dummies do not yield exhaustive data, and tests with a human being are not always possible), the over-all complexity of the solution to this problem becomes clear. The escape of an aircraft crew in the case of an emergency assumes the solution of problems pertaining to entire complex of equipment (the cockpit – [ejection] seat – parachute system – high-altitude equipment – portable emergency supplies).

Ejection as a means of forced escape from an aircraft can save the life of a pilot in unanticipated and completely unforeseen situations.

We know, for example, of a case in which a pilot was ejected under water; the events were the following.* Upon takeoff from an aircraft carrier the aircraft suffered engine failure; after ditching in the sea, the aircraft sank. Since the hydrostatic pressure prevented the pilot from forcing the canopy, the pilot elected to eject himself. Because his lifejacket was automatically inflated, he floated to the surface and was rescued.

As was pointed out earlier, the need for the development of ejection seats was brought about primarily by the rise in aircraft indicated speeds above 400 km/hr. In the foreign press the opinion has frequently been stated that with the continued rise in indicated aircraft velocities the ejection seat will be replaced by more perfect escape facilities such as, for example, ejection capsules or cockpits entirely separable from the aircraft.

§2. BRIEF REVIEW OF STATISTICAL DATA ON IMPLEMENTATION OF EJECTION SEATS

In 1957 the statistics of USAF experience with ejection seats were published.*

These data on the results of ejection involving human beings are presented in Table 1 and in Fig. 1.

TABLE 1

1 Травмы	2 Количество катапультирований	%	1 Травмы	2 Количество катапультирований	%
3 Нет	316	42	5 Тяжелые	110	14
Небольшие 4	158	21	Смертельные 6	173	23

1) Traumas; 2) number of ejections; 3) none; 4) minor; 5) serious; 6) fatal.

As we can see from Fig. 1, the percentage of unsuccessful ejections rises sharply for low and great heights, since the ejection seats employed by the USAF at that time were poorly adapted for heights below 300 m or for operations above altitudes of 10,000 m.

The average percentage of unsuccessful ejections in the intermediate range of altitudes (about 20%) also indicates the absence of

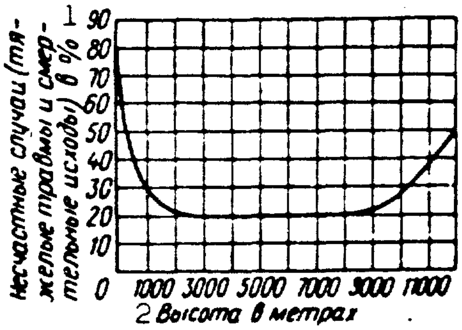


Fig. 1. Number of fatal or near-fatal landings as a function of ejection height. 1) Fatalities and serious injuries, in %; 2) altitude, in meters.

total safety in escaping from an aircraft under emergency conditions. The curve shows that up to a certain limit, the greater the altitude, the fewer ejection failures. This conclusion, as explained by foreign specialists, indicates that at low altitudes too much time is required to actuate the parachute systems and that the reliability of the automatic systems is inadequate (as a matter of fact, the time required for the normal operation of the automatic equipment is too long for the time available); with regard to high altitudes, this conclusion indicates defects in the parachute system and in the oxygen-supply system.

On the basis of the data presented in that same source, the number of ejection failures in the case of an aircraft operating in a nonsteady regime (climbing, in a spin, turning, spiral, roll, or dive) amounts approximately to 40%. The increase in the number of ejection failures in nonsteady regimes is explained by the difficulty which the pilot encounters in assuming the proper initial position.

Even this brief review of the statistical data pertaining to flights at low indicated velocities (89% of the ejections were carried out at velocities below 750 km/hr), shows the over-all complexity of the problem involved in ensuring safety in emergency ejection from a contemporary aircraft.

§3. DIFFICULTIES IN ENSURING EMERGENCY-EJECTION SAFETY IN THE CASE OF A MODERN AIRCRAFT

The difficulties in ensuring safety in emergency escape from an aircraft are governed by the following set of circumstances.

1. The potentials of the human organism which restrict the tolerable G forces, angular velocity, ram pressure, etc.

Special devices make it possible to expand the range of tolerable limits, but the design of such devices proves to be extremely complex.

2. The necessity of implementing safety devices over a wide range of altitudes, velocities, and aircraft attitude.

In terms of velocity the range of ejection-seat implementation may, for example, extend from 300 to 1200 km/hr.* The aerodynamic forces operating on the seat change by a factor of more than 16 over this range. This complicates the possibility of stabilizing the seat at the indicated velocities, and it also complicates the possibility of eliminating the harmful effect of the deceleration forces and angular velocities which are functions of the ram pressure.

Taking into consideration the great range of ejection-seat implementation with respect to altitude (from 0 to 25,000 m), we find it necessary to coordinate a number of the contradictory requirements imposed on the parachute system. For example, at low altitudes it is necessary to have the main parachute, which is the one which saves the individual, open as quickly as possible; at high altitudes, on the other hand, we must achieve a stabilized rapid descent from the high altitudes, having the main parachute open up only at 3-4 thousand meters.

3. The necessity of more complete automation of the escape operation, taking into consideration the likelihood of loss of consciousness (although only for a brief period of time), as well as the improper actions of the individual. In practical terms, this means that after the pilot has actuated the ejection lever, all remaining operations must proceed independently of the pilot in the required sequence, with regard to the intervals that depend on the altitude and velocity

of flight.

4. The necessity of providing manual back-up controls for operations executed by the main seat mechanisms, bearing in mind that in the case of an emergency the automatic system may fail.

5. The ejection seat must provide for crew safety not only in the case of aircraft emergency, but in the case of a forced landing which may be accompanied by considerable longitudinal acceleration. If in this case the individual is not adequately strapped to his seat, he may suffer injury as a result of being thrown forward against the steering column or the instrument panel.

6. The rescue facilities should not complicate aircraft control.

The evaluation of an ejection seat from the standpoint of its ability to satisfy the above-enumerated requirements should be approached with consideration of the probability (occurrence) of a given type of emergency situation. For example, comparing a seat ensuring 100% safety in the case of straight flight and only 50% in the case of maneuvering flight with a seat which provides 75% safety under all conditions, we should give our preference to the first seat since approximately 70% of all ejection occurs under conditions of straight flight. In other words, with mass application the first seat will provide emergency-ejection safety in 85% of all cases, whereas only 75% safety can be achieved with the second seat. Generally, whenever a range of implementation is increased by an even insignificant impairment of safety conditions it becomes extremely important to weigh carefully whether such an "improvement" will not lead to a rise in ejection failures.

These considerations are fully applicable to the problems of back-up controls. If the back-up system impairs the basic system in any manner, no matter how slight, in the majority of cases it is inexpedient to employ such a duplicate system.

§4. DIRECTION OF ACCELERATION EFFECT WITH RESPECT TO THE HUMAN BODY

Without going into the physiological aspects of the tolerance limits for a human organism with respect to acceleration and angular velocities, we will present the maximum tolerances considered acceptable at the present time.

For our purposes it is sufficient to establish four directions in which the G forces operate with respect to a human body, and these are known as (Fig. 2): 1) "pelvis-head"; 2) "head-pelvis"; 3) "chest-back"; 4) "back-chest."

In the case of downward ejection the G forces act in the "pelvis-head" direction; when catapulted [ejected] upward the individual experiences G forces in the "head-pelvis" direction, etc., i.e., always in the direction opposite to acceleration.

It should be borne in mind that the tolerable G forces are strong functions of the duration of their effect. The greater the duration, the lower the maximum G-force tolerance.

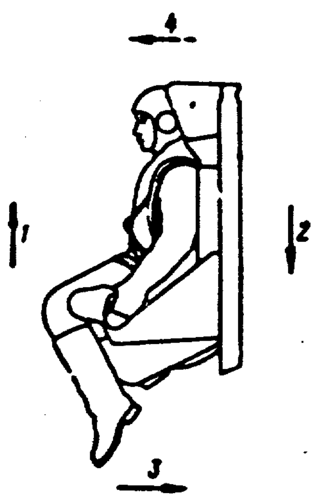


Fig. 2. Basic G-force directions. 1) "Pelvis-head"; 2) "head-pelvis"; 3) "chest-back"; 4) "back-chest."

Figure 3 shows a graph of the maximum G-force tolerances for various directions as a function of the duration of their effect.*

In addition to the limit values of the G forces, it is also necessary to know the maximum value of the angular velocities which a human being can withstand. At the present time it is the practice to hold that a human being is capable of withstanding an angular velocity of up to 2 revolutions per second, i.e., up to 12.3 radians per second. When we speak of limit values of G forces in a given direction we mean the maximum value of the G

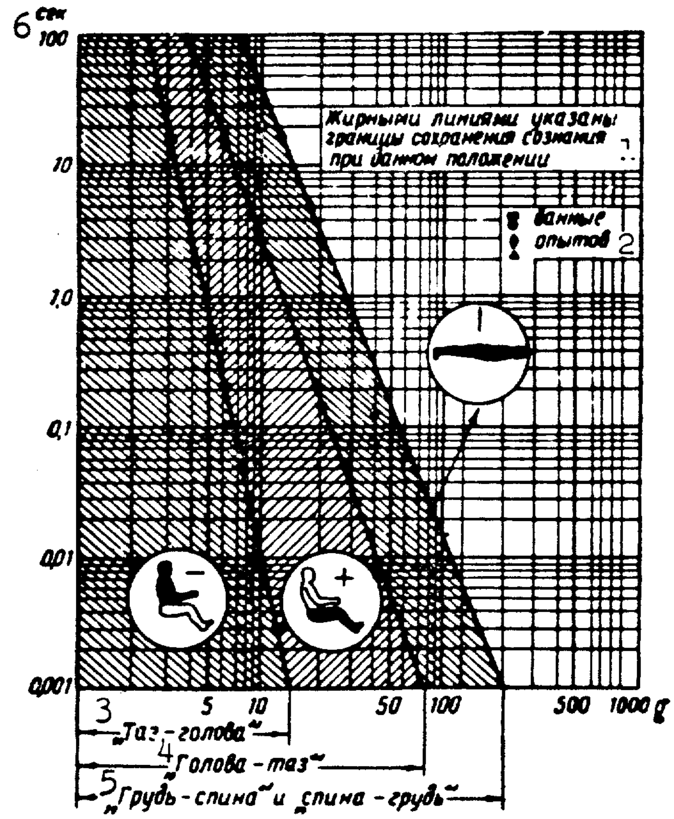


Fig. 3. Tolerable G forces as a function of time. 1) The solid lines indicate the consciousness boundary for the given position; 2) experimental data; 3) "pelvis-head"; 4) "head-pelvis"; 5) "chest-back" and "back-chest"; 6) sec.

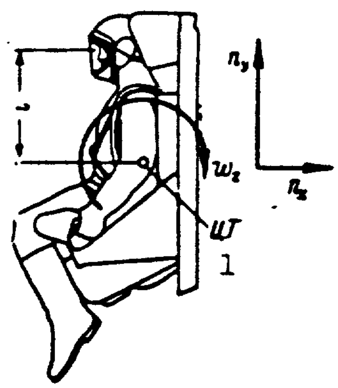


Fig. 4. Simultaneous effect of linear G forces, angular velocity, and angular acceleration. 1) Center of gravity.

force, if only at a single point on the body. In other words, with the simultaneous effect of linear acceleration, angular acceleration, and angular velocity the maximum local value of the linear acceleration, beginning from the head, is taken as the theoretical [maximum] magnitude.

The maximum G force is determined by the following formulas (Fig. 4)

$$n_{x\,max} = n_x + l\frac{d\omega_z}{dt}\frac{1}{g},$$

$$n_{y\,max} = n_y + l\omega_z^2\frac{1}{g}.$$

In the general case, the formulas become somewhat more complicated. In all doubtful cases the engineer should not make use of the solution without consulting with a medical specialist.

When we refer to a doubtful case we have in mind the combined effect of linear acceleration and rotation, resulting in an irregular change in the G forces.

For the preliminary evaluation of the tolerance of a given regime, it is also necessary to take into consideration the rate of change in the G forces. The maximum permissible rates of change in G forces are generally assumed to be equal to 250-300 per second in the direction "head-pelvis" and 500-600 per second in the direction "back-chest" and "chest-back."

§5. EJECTION SEAT EQUIPMENT

The following units (Fig. 5) should be distinguished on the basis of ejection-seat designation.

1. The actual seat, consisting of the bucket, backrest, headrest, and the mechanism for regulating the relative positions of these in terms of the pilot's height.

2. Power source for seat operation (firing mechanism and reaction-thrust booster), imparting an initial linear velocity to the seat that is adequate to eliminate the possibility of colliding against the frame of the aircraft.

3. Ram-pressure protection devices: a face guard visor (a curtain seat); arm and leg restraining devices to prevent the arms and legs from "flailing," and from the injury and pain that might be caused by the compression of the extremities to the seat by the ram pressure. Among these devices we should also include the protective (high-altitude) clothing (first of all, the helmet and boots).

4. Seat stabilization units, which provide for the proper posi-

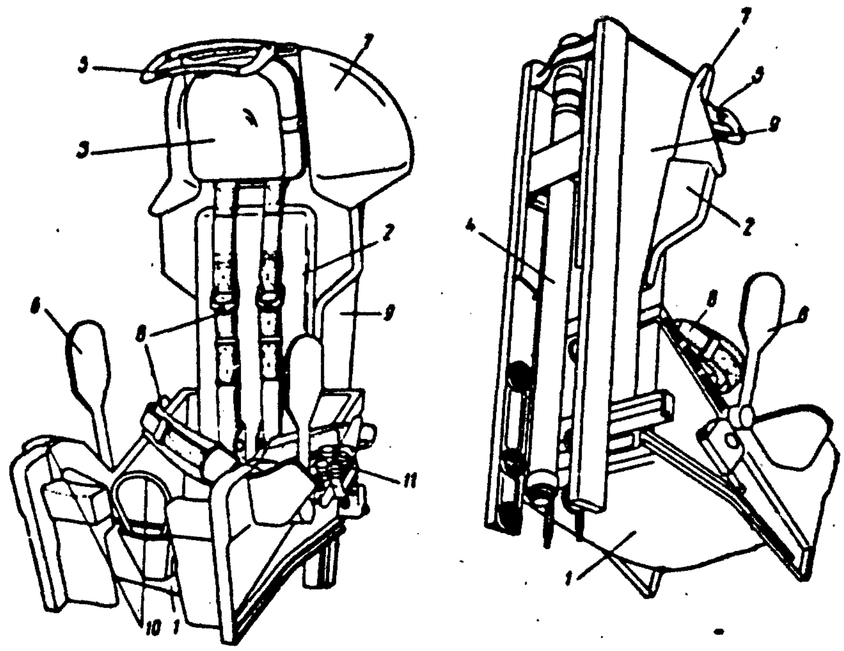


Fig. 5. Basic devices employed in contemporary ejection seat. 1) Bucket seat; 2) backrest; 3) headrest; 4) firing mechanism; 5) visor; 6) device to restrain arms; 7) stabilization panels; 8) harness straps; 9) parachute-system container; 10) seat control levers; 11) separation mechanism.

tion of the seat upon its entry into the airstream and limit the angular velocity of its rotation. These include the stabilization parachute (with or without a retractable rod) and stabilization panels (either fixed, or extendable).

Contemporary ejection seats are noted for their relatively high centers of gravity, and thus without stabilization devices they tend to turn end over end. This is an intolerable situation since it would, in this case, be impossible to actuate the parachute system and the G forces act in a useless direction, i.e., "pelvis-head."

These circumstances made it necessary to introduce special stabilizing devices into [ejection]-seat design.

5. Harness and suspension systems with fast-action releases, to strap the man to the seat and the parachute system.

6. The forced-posture system provides for the proper position that must be assumed on ejection and eliminates the dangerous weakness

of the harness system.

7. <u>The parachute system</u>, generally consisting of three parachutes: a) a stabilizing parachute which provides for the stabilization of the seat at the initial instant of time; b) a brake chute (opening when the speed of the seat has dropped off to a magnitude permitting the actuation of this parachute) which ensures a stable descent from great altitudes to heights at which the main parachute can be opened; c) the main rescue parachute which is actuated at a comparatively low altitude (where it is possible to exist without oxygen equipment).

Among the devices employed in the parachute system we should also include the following: the guns which release the first and occasionally the second chutes, and the spring locks which connect the parachutes to the aircraft, etc.

8. <u>The control system.</u> This is an automatic system which provides for the normal operational sequence of all units and the properly timed actuation of all stages of the parachute system after pressure has been applied against a single lever; the backup control system makes possible manual actuation of the most important links of the crew-rescue system (the release of the pilot or main parachute, separation of the individual from the seat, etc.).

The block and release functions which eliminate possible errors in seat control are also included in the control system; under unusual circumstances these functions might permit an unusual sequence of operations to occur (for example, ejection through the canopy).

In order to reduce the force required to actuate the control levers of the ejection seat, in many cases it becomes necessary to incorporate amplification devices, i.e., mechanical or pyrotechnical. These must also be included as part of the control system.

9. <u>The oxygen supply system</u> has a separation device which ini-

tially releases the seat from the aircraft, then releases the man from the seat, and switches the supply of oxygen from the on-board system to the emergency system carried by the man.

The portable emergency kit which should provide for the well-being and safety of an individual after landing (or ditching in the sea) should also be included in this equipment grouping.

10. Auxiliary units which provide, for example, for the raising or lowering of the seat (to facilitate entry into or exit from the aircraft) or the shifting of the seat in the forward-backward direction (to facilitate access to control and communications equipment) or changing the angles of seat position (to place the seat in a position that is convenient from the standpoint of resting). Depending on the engineering flight data for the aircraft, certain seat units may be lacking or, conversely, the seat may have been equipped with additional special units.

§6. PROCEDURE FOR ABANDONMENT OF CONTEMPORARY AIRCRAFT UNDER EMERGENCY CONDITIONS

Figure 6 shows the procedures involved in the emergency evacuation of a contemporary aircraft. The pilot, having decided to abandon the aircraft, must assume a particular position, depending on the type of ejection seat employed. Figure 7 shows the three most commonly employed positions, i.e., "hands on curtain"; "hands on handrails"; and "hands on center hold." In all cases the pilot's hands are positioned on a specific lever. After the actuation of this particular lever, the following operations must be carried out in sequence:

1) the actuation of the compulsory-position harness, correcting the pilot's posture, if incorrect, and taking up the slack in the harness;

2) jettisoning of canopy;

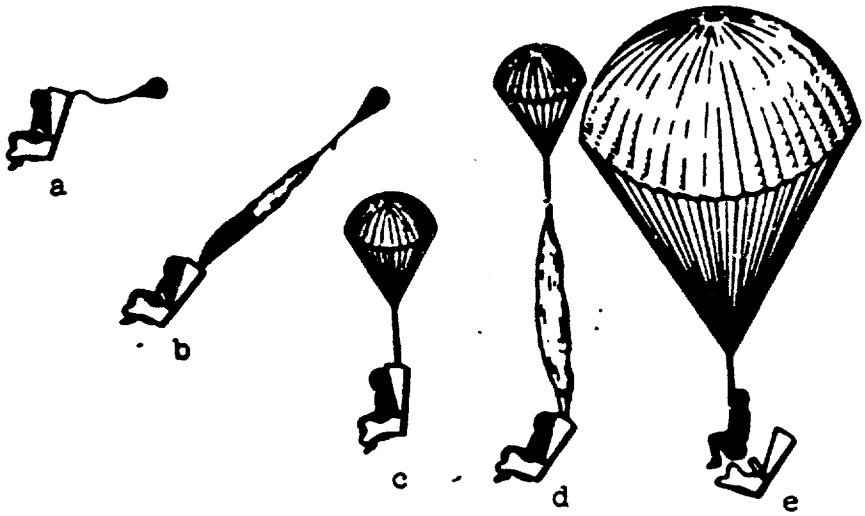


Fig. 6. Basic stages in emergency ejection procedure. a) Instant of ejection (stabilizing parachute fills out at the instant that the seat leaves the guide rails); b) opening of brake [pilot] parachute (freeing of stabilizing parachute by automatic release); c) stabilized descent; d) pilot chute pulls main canopy out; e) filling out of main-parachute canopy.

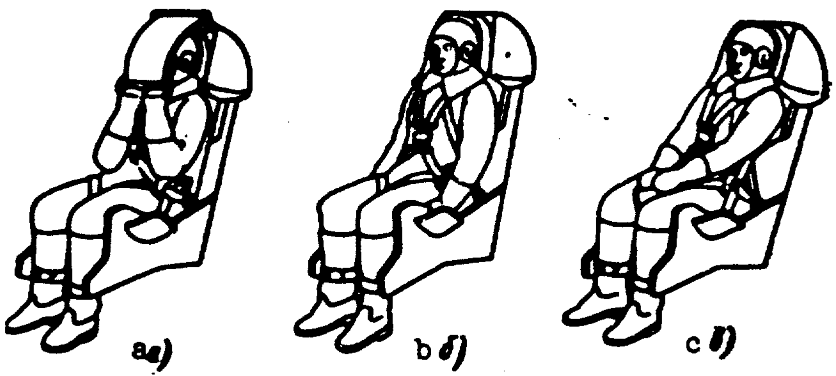


Fig. 7. Positions prior to ejection. a) Hands on curtain; b) hands on handrails; c) hands on center hold.

3) actuation of firing mechanism;

4) actuation of arm and leg restraining devices, these preventing the extremities from "flailing" in the airstream;

5) as the seat moves along the guide rails, prior to the instant at which the seat leaves the cockpit, the first stabilizing parachute must be ejected or the stabilizing panels must be extended (the stabilizing parachute is generally ejected by means of a special pyrotechnic

device, i.e., "a gun"); stabilization in the first instant after ejection of the seat into the airstream is an absolute necessity in order to ensure the required seat position until the start of the following operation (the ejection of the following parachute), in order to prevent intolerable angular velocities and in order to keep the seat from turning end over end. The required degree of stabilization can be achieved without stabilizing devices, by keeping the center of gravity for the seat and the pilot sufficiently low, but structurally this is not always possible and for this reason it is necessary to stabilize the seat with panels, a parachute, or a combination of the two;

6) the combined action of the panels and the stabilizing parachute should provide for the stabilization of the seat and limit the maximum speed of rotation over a period of time adequate to reduce the velocity of the seat to 500-600 km/hr;

7) at this speed the brake [pilot] parachute should be actuated, this chute providing for a stabilized descent to heights of 3-4 thousand meters (stabilized descent from high altitudes is necessary, since the extended turning in an uncontrolled free fall may result in serious consequences for the parachutist);

8) upon attainment of the required altitude, the main parachute is pulled out and the harness releases binding the pilot to the seat are opened; the pilot leaves the seat and descends to the ground by means of his parachute.

A portable emergency kit* is frequently made part of the suspension system; this kit contains all of the materials required to provide for first aid and sustenance for several days (it includes food supplies, medical supplies, communications facilities, a boat, skis, hunting and fishing equipment, etc.). This NAZ [portable emergency kit] must be capable of maintaining an individual under the most varied of conditions, i.e., in forests, deserts, at sea, etc.

In each specific case the above-cited procedure of ejection may be altered slightly, but in the general case all of the above-indicated elements of the ejection system must be incorporated in the design of a contemporary ejection seat.

In an ideal case all ejection procedures must be executed automatically, in the proper sequence.

Generally, the most important links of this system are provided with manual back-up controls. In the majority of cases the device to release the pilot from the seat is duplicated (manual release) and duplicate controls are also provided for the ejection of the brake [pilot] or main chutes. The backup-system makes it possible for a member of the aircraft crew to eject the pilot chute in the event that the stabilizing chute or its releases fail to function properly, or he can cause the billowing out of the canopy of the main parachute in the event that any or all of the elements of the safety system which should come into play prior to the opening of the main parachute fails to function.

The most reliable procedure is providing a back-up control for the ejection of the main parachute, i.e., duplicating the concluding link of the rescue system.

§7. CLASSIFICATION OF EJECTION SEATS

The classification of contemporary [ejection] seats has not yet been fully established and for this reason it is only tentative in nature in the present work.

Contemporary ejection seats may be classified in accordance with a variety of indicators.

[Ejection] seats are frequently classified according to aircraft type for which they are intended, i.e., distinctions are made between seats for fighter and bomber aircraft, and these in turn are divided into seats for pilots, navigators, etc.

Ejection seats for fighter aircraft are the simplest, since they are intended for use over only a comparatively short period of time. The design for bomber seats in which crew members must spend many hours must provide for a rest position, i.e., provision must be made for changing the angle of the seat, and in the case of certain specific crew members (the navigator, the gunner, and the radio operator), provision must be made moreover for shifting the seats in the longitudinal direction or for rotating them about the vertical axis. In certain cases the seat must simultaneously serve as a lift, i.e., it must provide for vertical shifting.

Seats are distinguished on the basis of ejection direction, i.e., up and down. Downward ejection raises the minimum height of safe ejection and makes it impossible to achieve rescue in the event of a take-off emergency. However, we have encountered cases (with long fuselage lengths and great flight velocities) in which downward ejection is the simplest method.

As has already been pointed out, seats are distinguished on the basis of the position assumed by a crew member prior to ejection.

Until very recently the positions involved "hands on handrails" or "hands on curtain," but now there is also the position of "hands on the center lever."

The curtain is inconvenient in the case of flight involving the use of special helmets; flight at great altitudes, however, demands that the pilot wear an airtight helmet. Therefore, the curtain seat is not employed at great altitudes. The position "hands on center lever" makes it possible to reduce the dimensions of the seat somewhat and also facilitates the extent to which the effect of the ram pressure can be withstood.

Seats can also be classified on the basis of the parachute systems employed, i.e., multistage, two-stage (without stabilizing or pilot parachutes), or even single stage.

The most common forms of operational parachute storage are the following:

a) in the bucket of the seat;

b) "soft" storage, directly in the backrest of the seat;

c) parachute storage in rigid container behind the backrest of the seat;

d) the pilot's back [seat] pack parachute.

Combined versions of the foregoing are encountered, for example, where a portion of the system is carried in a rigid container, while the remainder is placed in the bucket portion of the seat, etc.

On the basis of control systems. [Ejection] seat control may be manual in which case all operations are carried out through the application of human muscular force; mechanical control involves the application of muscular force against spring boosters (tensioned in advance) which carry out the required operations; and finally, there are pyrotechnical devices in which the human being has only to explode a cartridge, with all of the work being carried out by the system of pyromechanisms.

We frequently encounter a combined system in which manual drive is combined with pyrotechnical mechanisms.

According to the stabilization system. There are cases in which [ejection] seats are stabilized by fixed or extendable panels (the fixed panels increase the dimensions, cannot always be accommodated in the cockpit, and they impair the view in back) and stabilization by means of a special parachute installed either directly in the back of the seat or on a retractable rod (to increase the moment).

According to the harness systems. There are two types of harness systems, i.e., composite and separate. With a composite harness system the same straps are used to strap the man to the seat (the harness system) and to the parachute (the suspension system). Despite the advantages of the composite system, separate harness systems continue to be used.

According to the devices to protect extremities against flailing as a result of ram pressure. These devices are classified as "hard" when involving solid restraining means and "soft" when restraint is achieved by means of a soft capron stretchable net at the sides of the seat during the ejection (Fig. 8).

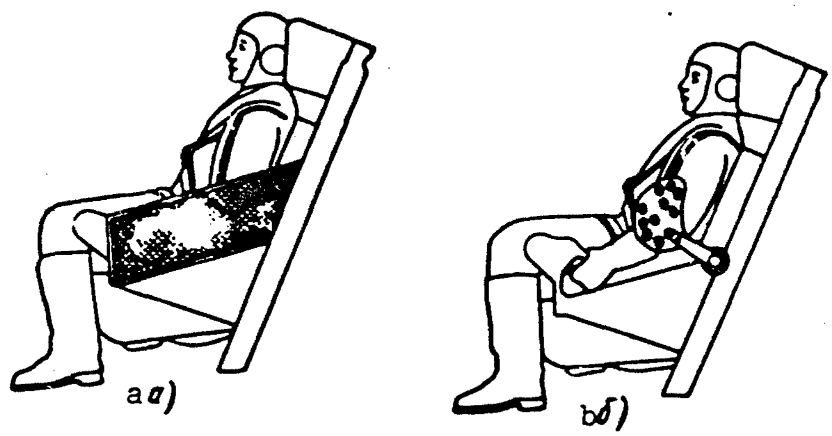


Fig. 8. Soft protection (a) and hard arm restraint (b), to prevent flailing of arms as a result of ram pressure.

According to the method of protecting the head (face) from the airstream, we can distinguish the method of a soft curtain (in this case the pulling down of the curtain releases a signal to actuate the firing mechanism) and the method involving protection by means of a helmet (Fig. 9). Finally, hypothetically we can imagine that the canopy is not jettisoned on ejection and the seat, turned to the proper position, is separated together with the canopy (Fig. 10).

Fig. 9. Various methods of protecting the face against ram pressure. a) Curtain; b) helmet.

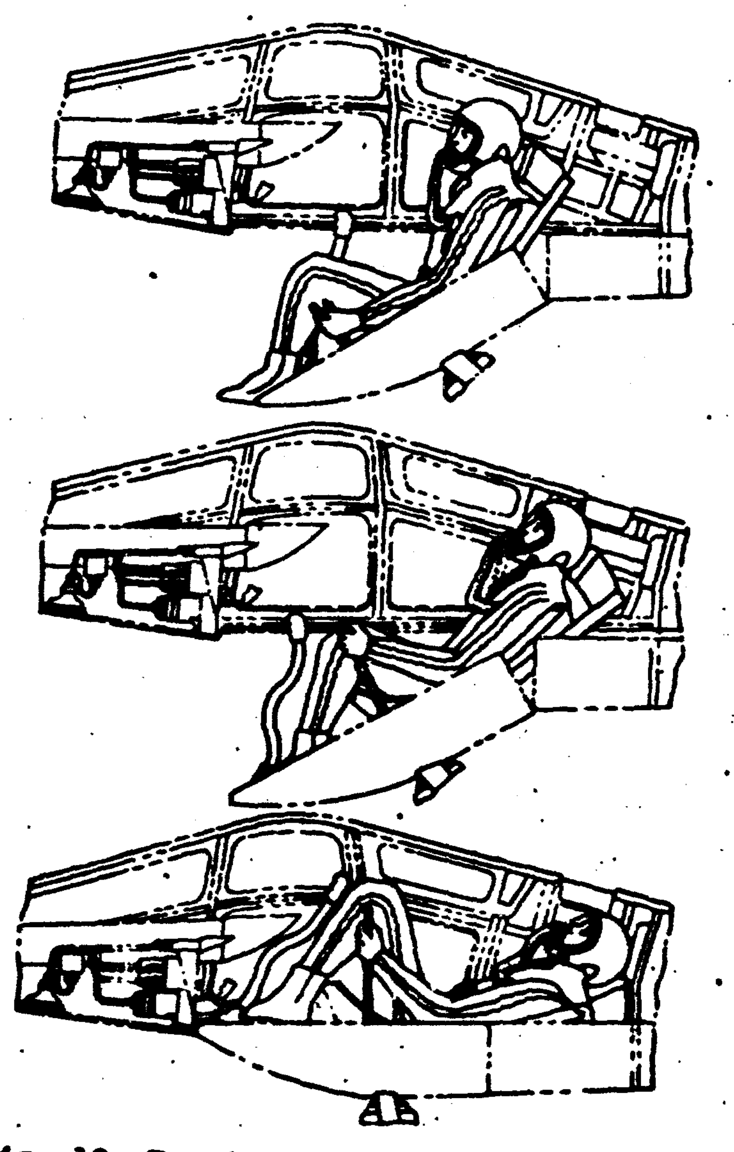


Fig. 10. Turning of seat prior to entry into airstream.

In order to protect the face we can also employ complete or partial encapsulation.

It is the opinion of foreign specialists that the systems of "hard" protection exhibit two significant drawbacks, i.e., they make it difficult to separate the man from the seat and they increase the complexity of the harness system. In the case of "hard" protection of the face or of the entire body the ram pressure will not act against the man to press him back into the seat and, consequently, the man will rise in the straps of the harness system under the action of deceleration G forces. Since the area of the harness system is considerably smaller than the area swept by the airstream, specific pressure rises. However, it is particularly difficult in this case to protect the head against being forward vigorously.

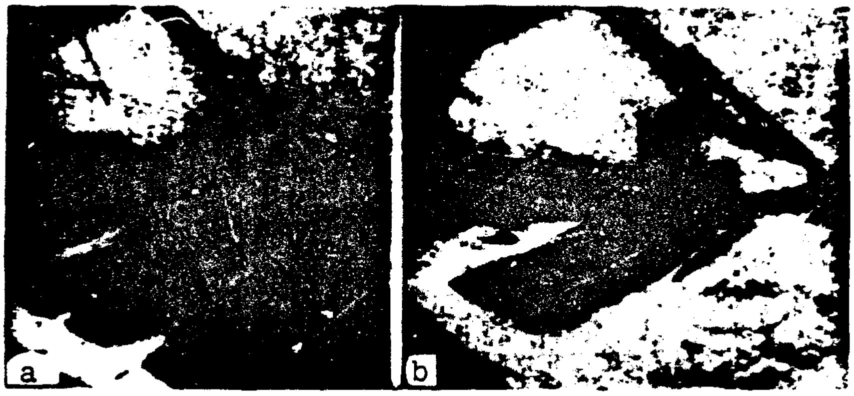


Fig. 11. Effect of protective deflector in the case of flow past a model D seat. a) Without deflector; b) with deflector.

It is possible to protect a human being against the effects of ram pressure in the case of flights at high speeds (with $M > 2$) by setting up an artificial system of shock waves. In order to produce these shocks in front of the seat (Fig. 11) a deflector panel is extended on a special rod to produce a system of shocks behind which the ram pressure is reduced, producing a rise in static pressure.* This method is inadequately effective for low M(ach) numbers and high ram pressures, and such a system should generally be capable of effecting rescue over the entire range of velocities and altitudes. It is also possible to employ a method of canopy protection.

A brief review of the various structural and basic solutions which confront the designer of an ejection seat indicate the difficulty of classifying contemporary [ejection] seats and further point up the rather extensive arsenal of means from which the designer must decide upon the most appropriate selection.

During the planning stage the designer must take into consideration about 20 interrelated questions:

1) the type of aircraft (fighter, bomber, etc.), for which the particular [ejection] seat is intended;

2) the operating conditions for a given crew member (pilot, navigator, etc.);

3) the velocity and altitude at which ejection is a possibility;

4) the position which a pilot must assume prior to ejection;

5) the weight of the seat, its centering, and the moments of inertia with respect to the x, y, and z axes;

6) adjustment of seat according to pilot height;

7) desired width of emergency cockpit exit;

8) velocity and acceleration imparted to the seat by the firing mechanism;

9) seat stabilization system;

10) "hard" or "soft" protection for arms and legs;

11) face protection (curtain, helmet, "hard" guard);

12) ejection control (manual, mechanical, pyrotechnical, combined, actuated with curtain, by handrails, or with center lever); are manual back-up systems possible?;

13) the parachute system (1-, 2-, or 3-stage, ejected by means of

a gun or a spring lock);

14) the possibility of backing up the [parachute] ejection (2nd or 3rd stage);

15) storing of parachutes in a container, in the seat bucket, on the person;

16) compulsory positioning;

17) the existence of and operational life of the parachute oxygen equipment;

18) the presence of and position of the portable emergency kit (in the seat or on the back);

19) the pilot's high-altitude equipment (a spacesuit, a pressure suit, flight clothing);

20) additional mechanisms (blocking devices, the mechanism for the shifting of the seat within the aircraft).

§8. EJECTION-SEAT TESTING

It follows from the above that the ejection seat used at low and high altitudes in the case of flight velocities in excess of 1000 km/hr (indicated) is one of the most complex units in a contemporary aircraft. The operational failure of any element of the seat, beginning with the firing mechanism and ending with any of the harness releases, may produce fatal results. Each element of the seat, each unit of the seat, must be subjected to verification calculations and laboratory tests, and the entire seat must be tested on special test equipment simulating flight conditions.

It is the world-wide practice of testing ejection seats with: 1) a vertical catapult which makes it possible to check on the functioning of the firing mechanism, the exit of the seat from the cockpit, and the effect of vertical acceleration on the seat (Fig. 12);

2) in a wind tunnel, in which the seat is swept by a flow exhibit-

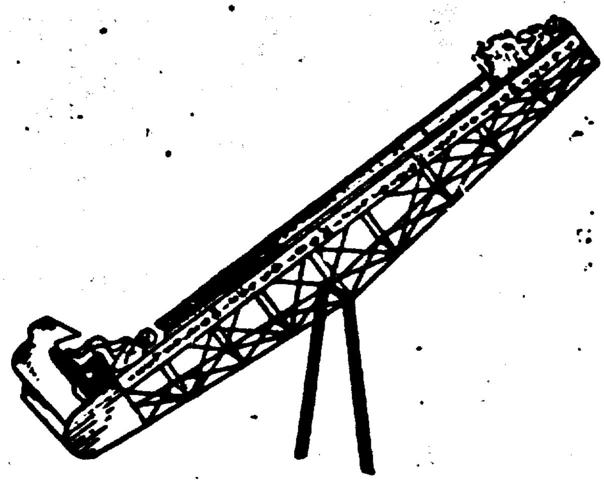


Fig. 12. Vertical ejection installation to test the effect of ejection G forces.

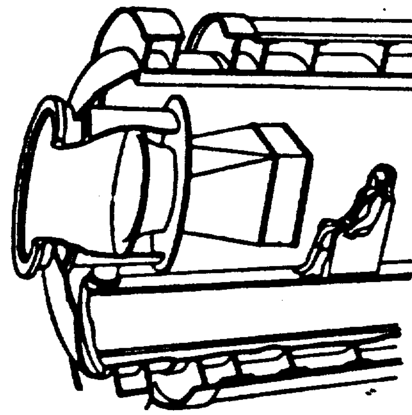


Fig. 13. Seat with dummy in wind tunnel.

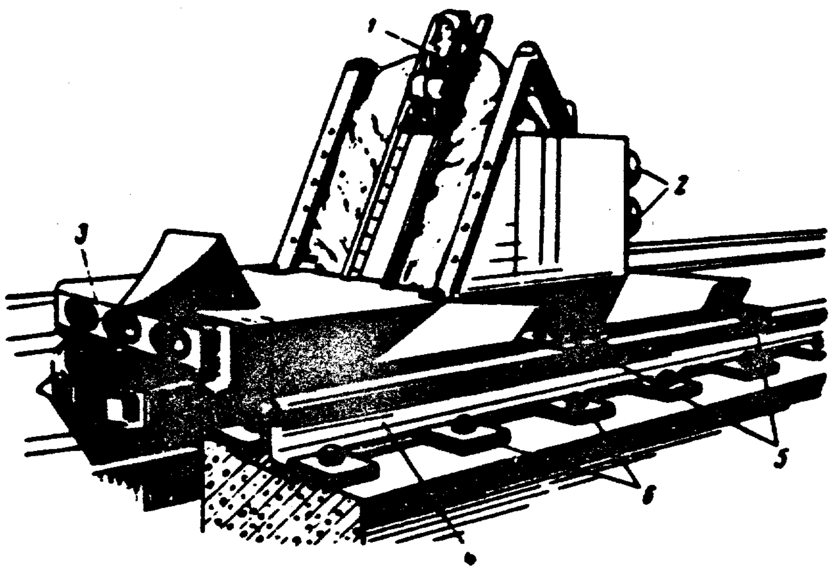


Fig. 14. High-speed sled with reaction-thrust engines to test ejection seats. 1) Dummy; 2) reaction-thrust booster; 3) sled; 4) guide rails; 5) runners; 6) tie plates.

ing realistic ram-pressure values (Fig. 13);

3) with a special sled capable of developing realistic horizontal accelerations and (desirably) velocities (Fig. 14).

All tests carried out on these installations are first performed with dummies and then with human beings. After the successful passage of ground tests, the seat must be subjected to conclusive tests, i.e., flight tests. As in the case of ground test installations, the flight tests are initially carried out with dummies and then with human beings. Only after having passed all the tests and after a determination has been made of the factors which might produce high or low temperatures and vibration regimes in the aircraft can the seat be considered operational. A unique feature of the seat in comparison with other aircraft units is the fact that it remains operational throughout its entire service life without ever being used under emergency conditions. If on the basis of the remaining aircraft assemblies we obtain information during the operational process with respect to defects and maladjustments and, consequently, with respect to the need of adjusting or repairing an assembly, the seat may for the first time be employed as a safety measure even a short period prior to the completion of its service life. Thus the designer must provide as well for a reliable system of checking on the efficiency of the entire seat as a safety device, and this applies equally to all assemblies of the seat.

Manu-script Page No.	[Footnotes]
1	For a detailed discussion of this point see Armstrong, Aviatsionnaya meditsina, IL [Aviation Medicine, Foreign Literature Press], 1954; Voprosy aviatsionnoy meditsiny [Problems in Aviation Medicine], IL, 1954; Geratevol', Psikhologiya cheloveka v polete [The Psychology of Man in Flight], IL, 1956; K. Platonov, Chelovek v golete, Voyenizdat [Man in Flight, Military Press], 1957.
3	"Aero-Revue," 1959, February.
4	Aviation Medicine, 1957, No. 1, pages 69-73.
6	We have reference here to indicated speed.
8	Z. Geratevol', Psikhologiya cheloveka v polete, IL, 1956.
15	Known as NAZ in abbreviated form.
21	"Aviation Week," 1956, October. "Flight," 1956, November. "Interavia," 1957, February.

Chapter 9

HIGH-ALTITUDE AND PROTECTIVE EQUIPMENT

§1. GENERAL REMARKS

Individual contemporary high-altitude and protective equipment for aircraft crew members, as follows directly from the designation, is intended for the protection of an individual:

1) against a lack of oxygen and reduced barometric atmosphere pressure;

2) against the ram pressure of the air in the case of ejection;

3) against the effects of low temperatures;

4) against the effects of radiation energy and high air temperatures;

5) against the effects of acceleration (G forces), arising in the case of curvilinear flight during aircraft maneuvering;

6) against the individual's head accidentally being struck during the execution of maneuvers by the aircraft, in the case of forced landings, or when the landing is rough.

Moreover, the complex of individual equipment should, if necessary, provide for sea-rescue requirements, protection against excessive cold in the water, and some food reserve and signaling facilities in the event that the aircraft is forced down over water or a desert.

In conjunction with the oxygen-breathing and special equipment, the following forms of individual equipment, used in a variety of combinations with each other, in some measure satisfy the above-enumerated basic requirements:

1) high-altitude G suits;

2) high-altitude pressure space suits;

3) climatized [ventilated] suits;

4) antigravity devices;

5) protective helmets;

6) water survival suits;

7) portable emergency kit.

High-altitude G and pressure suits are used to protect against the harmful effects of low barometric pressure and oxygen starvation. Climatized [ventilated] suits supplied with conditioned air are used to protect the human body against both low and high temperatures. Antigravity [acceleration] devices reduce the harmful effect of prolonged acceleration in the head-to-pelvis direction. Protective helmets (including the airtight helmets of pressure and G suits) protect the pilot's head against ram pressure and accidental impact. Moreover, the protective helmet significantly diminishes the effect of radiated heat.

The designation of the water survival suit is self-evident (concurrently we note that the high-altitude pressure suit can also be employed for survival in the sea).

The portable emergency kit may be fitted out with various food products, distilled water, communications and signaling facilities, medication, fishing or hunting accessories, etc., depending on the geographic region in which the aircraft is operating.

In order to satisfy all the operational requirements, it is necessary to employ simultaneously several types of equipment such as, for example, a pressure suit, an antigravity suit, and a portable emergency kit. The selection of a given type of equipment depends on the specific operational conditions, on the altitude, velocity, and the duration of flight. In order properly to understand the operational principles, the area of application, and the potentials of the protective equipment, we must have some idea as to the influence of the physical conditions of flight on the human organism.

Below we present a very brief account of the influence exerted by high altitude on the organism. The effect of acceleration, temperature, and ram pressure will be examined in the description and evaluation of the corresponding protective equipment.

§2. EFFECT OF HIGH-ALTITUDE CONDITIONS ON THE HUMAN ORGANISM*

Oxygen Starvation

The oxygen content in the atmosphere amounts to 21% by volume and remains constant to altitudes of 70-90 km. Air pressure diminishes rapidly with increasing altitude and in relation to the ground air pressure is as follows:

at an altitude of 5500 m...................... 1/2
at an altitude of 8500 m...................... 1/3
at an altitude of 12,000 m.................... 1/5

*Above 15 km, from the physiological standpoint, flight conditions in terms of partial oxygen pressure are virtually equivalent to flight in interplanetary space.

The human organism requires a continuous supply of oxygen. The oxygen enters the blood through the lungs, and to make room carbon dioxide is liberated from the blood. In a state of rest a human being executes 15-16 breathing cycles per minute, inhaling approximately 0.5 liters of air with each breath. In the case of physical work, depending on its intensity, the inhalation rate increases to 20-25, and the average intake volume reaches 1.5-2 liters. The total volume of air inhaled in a single minute (equal to the product of the number of inhalations by the volume of a single inhalation) is known under the heading of lung ventilation. The interrelationship between lung ven-

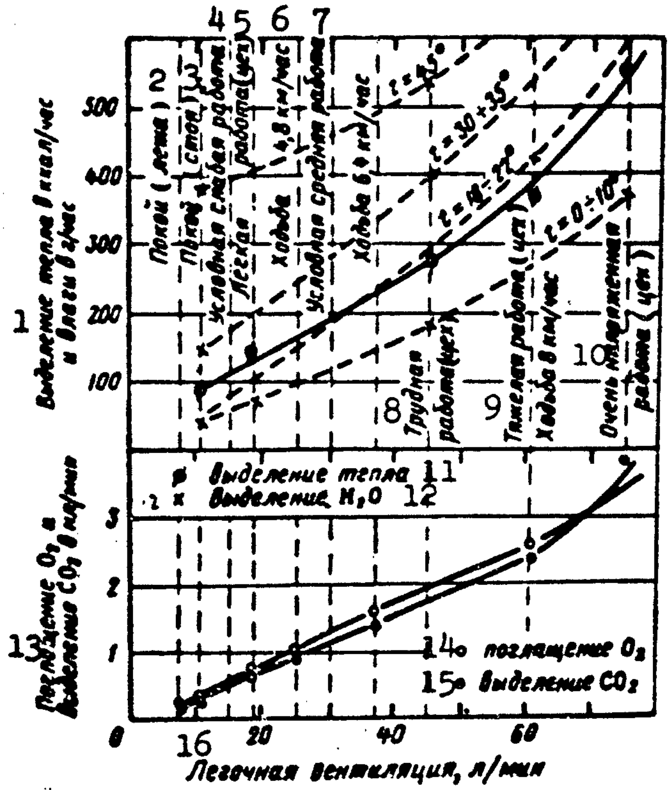


Fig. 168. The interrelationship between lung ventilation, intensity of work, the quantity of oxygen required, the liberation of carbon dioxide, moisture, and heat. For a flight crew it is assumed that the average work corresponds to lung ventilation of 15 liters per minute, while heavy work corresponds to 30 liters per minute. 1) Liberation of heat in kcal/hr and moisture in g/hr; 2) rest (lying down); 3) rest (standing); 4) conditionally easy work; 5) light work (shop); 6) walking, 4.8 km/hr; 7) conditionally medium work; 8) hard work (shop); 9) hard work (shop); 10) very intensive work (shop); 11) liberation of heat; 12) liberation of H_2O; 13) absorption of O_2 and liberation of CO_2 in standard liters per minute; 14) absorption of O_2; 15) liberation of CO_2; 16) lung ventilation, liters per minute.

tilation, intensity of work, the quantity of oxygen required, the liberation of carbon dioxide (CO_2), heat, and moisture is presented in Fig. 168. The curve showing the generation of heat is given for the temperature interval between 10 and 24°C. With a change in temperature from 24 to 45°, the rise in the generated heat in a state of rest amounts to 15%.

Under normal conditions a man's breathing is relatively shallow and after an ordinary expiration approximately 2.5 liters of air remain in the lungs. This air, known as alveolar air, contains 14.5 ± 0.5% oxygen and 5.5 ± 0.8% carbon dioxide. The indicated tolerances correspond to the varying intensity of the work performed.

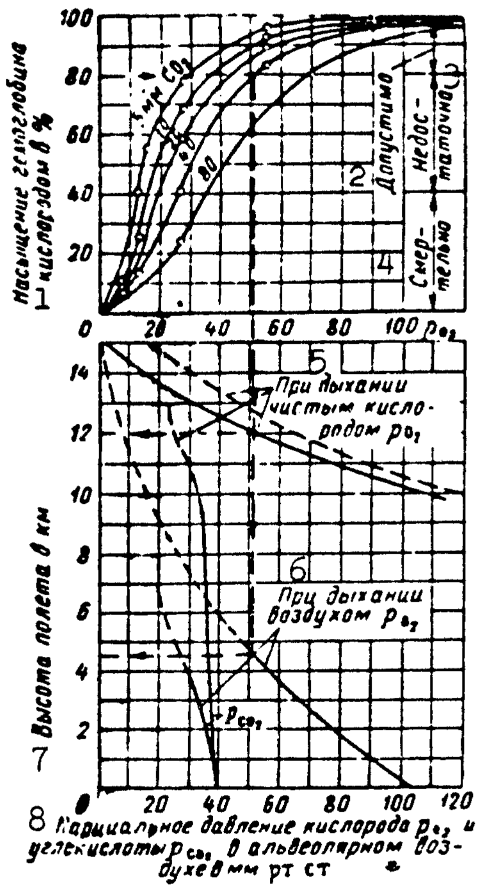


Fig. 169. The interrelationship between partial oxygen and carbon-dioxide pressures in the alveolar air, oxygen saturation of the blood, and flight altitude. The dashed lines in the lower graph correspond to a regime of hyperventilation. 1) Oxygen saturation of hemoglobin in %; 2) permissible; 3) inadequate; 4) fatal; 5) breathing oxygen; 6) breathing pure air; 7) flight altitude, in km; 8) partial oxygen pressure p_{O_2} and partial carbon-dioxide pressure p_{CO_2} in alveolar air, in mm Hg.

As early as during the second half of the last century, the physiologists Pol' Ber [sic] and I.M. Sechenov established that the oxygen saturation of the blood, which is a function of the partial oxygen pressure in the alveolar air, rather than of its percentage content in the blood, is of decisive importance for the state of the organism and the well-being of a human being at high altitudes.

The process of oxygen intake is one which involves the diffusion of this gas through the walls of the pulmonary alveoli which are covered with a dense network of blood-carrying capillaries. The incoming oxygen combines with the hemoglobin of the red corpuscles and is distributed by the circulation of the blood to all cells of the organism. It has been established that satisfactory functional human efficiency is achieved only if the oxygen saturation of the arterial blood is no less than 80%.

In the upper half of Fig. 169 we can see the results of experiments carried out by the physiologist Dzh. Barkroft [sic] (confirmed by other researchers as well), and these indicate the relationship between the oxygen saturation of the hemoglobin and the partial oxygen and carbon-dioxide pressures in the alveolar air. We can see from these curves that with partial oxygen pressures of 100 mm Hg and a partial carbon-dioxide pressure of 40 mm Hg, the oxygen saturation of the arterial blood amounts to 96%; in the case of an oxygen pressure of 50 mm Hg, the oxygen saturation of the arterial blood amounts only to 80%. With a continued drop in the partial oxygen pressure, the oxygen saturation of the blood drops off sharply.

Water vapors always saturate the lungs at a constant partial pressure of 47 mm Hg at a body temperature of 37°C, since the tension of the water vapors is a function only of the temperature and is independent of pressure.

The partial pressure of the carbon dioxide in the lungs at ground level, given a carbon-dioxide concentration of 5.5%, amounts to

$$p_{CO_2} = \frac{(760-47)\,5{,}5}{100} = 39{,}2 \text{ mm Hg.}$$

With increasing altitude, this quantity in the majority of individuals gradually diminishes to 35-20 mm Hg (see the lower portion of Fig. 169). The factor responsible for this reduction is the increase in the lung ventilation, the so-called hyperventilation which leads to the flushing of the carbon dioxide, with simultaneous increase in the partial oxygen pressure in the alveolar air. In the case of mountain ascents the partial carbon-dioxide pressure in the lungs diminishes to a greater extent than under conditions of conventional flight; this can be explained by the time factor. This is confirmed by the fact that a prolonged stay in a pressure chamber (up to 24 hours) yields the identical pattern as under mountain conditions.

Moderate work at medium altitudes (4-6 km) promotes an increase in lung ventilation and blood circulation, and this is an adaptive (compensatory) reaction of the organism to a lack of oxygen. However, a reduction in the carbon dioxide in the organism depresses the respiration center and lung ventilation again diminishes. Thus in the case of a flight aboard an aircraft in which the effect of mountain acclimatization is lacking, the adaptability of an organism to high-altitude conditions may be of but brief duration and quite limited.

The lower half of Fig. 169 shows the partial oxygen pressure in the alveolar air (when breathing pure oxygen and breathing atmospheric air) as a function of flight altitude. Comparing these curves with the graph on top, we see that an altitude of 4.5 km corresponds to 80% oxygen saturation of the blood, this being the boundary of satisfactory human efficiency when breathing air; when breathing pure oxygen, this corresponds to an altitude of 12 km.

The altitude of 12 km is also the physiological boundary within which a flight crew may execute flights using conventional oxygen equipment (i.e., the equipment which enriches the intake air with oxygen, but which does not generate elevated pressures in the lungs).

The reduction of the partial oxygen pressure in the intake air leads to a number of functional disturbances in a human being, and these are collected under a single heading, i.e., high-altitude sickness (oxygen starvation [anoxia]).* Below altitudes of 1500-2000 m the human organism does not react to a reduction in the oxygen content in the atmospheric air. At an altitude of about 2000 m, because of a reduction in the partial oxygen pressure, the brain cells are the first to experience a reduction in depth perception and night vision. Therefore, during night flights more oxygen should be used starting at an altitude of 1500 m, and during the day additional oxygen should be employed above 3500 m.

At altitudes from 3500 to 5000 m, particularly when the flights last for more than 3-4 hours and under conditions of physical or nervous stress, oxygen starvation results in a number of disturbances which disturb the balance between the inhibitory and excitatory reactions in the cerebral cortex. In some individuals (with an inhibitory nervous system) we note the development, first of all, of fatigue, depression, drowsiness, and headache; response is inhibited. In other individuals – whose nervous system is of the excitatory type – we find an elated mood, a tendency to increased activity, i.e., motor and verbal activity, while at the same time there is a dulling of the ability to analyze external phenomena, coordination of movement is disrupted, and the individual lacks awareness of the fact that he is experiencing a state of nonnormal sickness.

With increasing altitude or prolonged stay these two disturbance complexes intensify and may merge with one another. The primary danger and insidious nature of altitude sickness involves the fact that all of the above-enumerated symptoms are not clearly defined, the subject individual is not aware of their presence, and the transition from the lower degrees of the disturbances to the more serious takes place unnoticed, so that at an altitude of about 7500-8000 m, despite apparent well-being, a man loses consciousness. If oxygen is not applied immediately, or if the aircraft is not immediately brought to lower altitudes, respiratory paralysis and death result.

Tables 14 and 15 show the reserve-time values,* i.e., the time during which a man retains active awareness and minimum functional efficiency if suddenly exposed to some [high] altitude (for example, in the case of the depressurization of an aircraft cabin) or if the supply of oxygen from the oxygen equipment is suddenly cut off.

At an altitude of 15 km, even when breathing pure oxygen, we find

TABLE 14

Average Reserve-Time Values when Breathing Atmospheric Air (after Shtrukhgol'd [sic])

1 Высота в км	7	8	9	10	12	14	15	16
2 Резервное время в сек.	300	180	80	50	26	20	15	9

1) Altitude, in km; 2) reserve time, in seconds.

that the reserve time is equal only to 15 seconds. If an aircraft cabin becomes depressurized at an altitude above 15 km this is totally inadequate in order to permit the pilot to reduce the aircraft to a safe altitude of the order of 12 km. Thus, for example, in order to descend from horizontal flight at an altitude of 15 km to 12 km at speeds corresponding to 0.95 M ~50 seconds are required. For this reason, in the case of aircraft whose ceiling is higher than 13 km it became necessary to provide oxygen-survival equipment capable of ensuring respiration with pressurized oxygen.

TABLE 15

Average Reserve-Time Values when Breathing Pure Oxygen, not Pressurized (after V.A. Skrypin et al.)

1 Высота в км	13,5	14	14,5	15	16
2 Резервное время в сек.	300	50	30	15	9

1) Altitude, in km; 2) reserve time, in seconds.

Effect of Low Barometric Pressure

Independently of oxygen starvation, the human organism is harmfully affected by reduced barometric pressure. The influence of the ambient pressure becomes evident in the following forms:

1) pain in the joints and the surrounding tissues (the so-called decompression disturbances or aeroembolism);

2) pain in the gastrointestinal tract (high-altitude meteorism);

3) aeroemphysema (distension) of the subcutaneous tissues.*

Pain in the joints occurs at altitudes of 9000-13,000 m. A single individual may experience pain during one ascent, with no pain experienced during another ascent. Most frequently pain is experienced in the shoulder and knee joints. The intensity of the joint pains varies, i.e., from tolerable rheumatic pains to attacks of intense pain requiring the immediate descent from that altitude. With descent to 8000-7000 m the pain, as a rule, disappears. Joint pain generally sets in after 10-20 minutes after ascent to a great altitude or during the course of the first hour; however, pain may be experienced later on as well. In the case of a rapid ascent the pains are encountered more frequently than in the case of a gradual ascent. The conversion of the excess nitrogen from a dissolved state (which is the state in which it is encountered in the tissue cells) into a gaseous state is the factor responsible for the pain. Gas bubbles exert mechanical pressure against the nerve endings, and this produces the sensation of pain.

It is recommended that in order to prevent pain in the joints pure oxygen should be inspired for a period of 30-60 minutes prior to a high-altitude flight, and during this period there occurs the process of "freeing" (desaturation) of the organism of nitrogen.

Of the total quantity of nitrogen dissolved in the tissues, when breathing pure oxygen 1/3 of the nitrogen is eliminated within the first 15 minutes; then the desaturation process gradually slows down. During desaturation the process cannot be interrupted or the mask removed, since the entire effect would be lost and the desaturation process would have to be started all over again.

High-altitude meteorism is brought about by the expansion of gases in the stomach and in the intestine. If during an ascent the gases fail to pass out through the system in natural ways, the volume of the gases and their pressure against the walls of the gastrointestinal tract increase, thus resulting in pain, the raising of the diaphragm, a reduction in lung capacity, and a number of other disruptions which disturb the normal state of the organism.

In particular, it is possible that the meteorism promotes the appearance of pain in the joints at high-altitudes, since with reduced inspiration the liberation of excess nitrogen from the organism through the lungs is diminished.

At great altitudes (10-13 km) meteorism may be responsible for extremely acute attacks of pain. These attacks in turn may lead to a number of vegetative disturbances (perspiration, rate of heart activity, etc.).

In order to prevent high-altitude meteorism it is necessary to maintain diets eliminating the formation of intestinal gases and ensuring normal functioning of the intestine.

Aeroemphysema of subcutaneous tissues occurs when the ascent is to altitudes above 20 km at those portions of the human body which are not subject to counterpressure. Thus, for example, if the ascent to the indicated altitude were carried out in a high-altitude suit without the proper gloves, within 5-10 minutes after the ascent the unprotected hands become distended and after about 15 minutes the fingers have increased in volume to such an extent that it is impossible to perform any work with the hands [2].

The immediate factor responsible for the "swelling" of the hands is the formation of gas bubbles between the muscles and the skin cover, these bubbles causing delamination of the subcutaneous cellular tissue. This phenomenon is brought about primarily as a result of physical factors. We know that at an ambient pressure of 47 mm Hg (19,100 m) water boils at 37°C. Since the human organism contains about 70% water, and the temperature of the body is 37°C, it is natural that at altitudes in excess of 19,100 m intense evaporation of fluids from the tissues of the human body occurs. The water vapors accumulate beneath the skin and force it away from the muscles. After dropping to an altitude below 17,000 m, we find that subcutaneous distension disappears rather rapidly and leaves no trace.

Solar Radiation, Ozone, and Cosmic Rays

The radiative energy of the sun at the upper boundary of the atmosphere is regarded as a constant quantity and on the average amounts to 1.94 cal per 1 cm^2 of surface per minute. At sea level in clear weather this magnitude does not exceed 1.52 cal. Above the clouds, starting from altitudes of 10-12 km the energy of solar radiation is equal to 1.78 cal and gradually increases to its limit. During the day the intensity of solar radiation increases from 0 to the maximum and again diminishes to 0 with the onset of darkness.

The thermal effect of solar radiation is caused primarily by the infrared portion of the spectrum. Infrared rays are actively absorbed by water vapor. Therefore, with increasing altitude we find a direct relationship between the reduction in moisture content and the intensity of the infrared rays.

The intensity of the ultraviolet radiation on the average increases by 3-4% with each 100 m of ascent in comparison with its value at sea level. This occurs as a result of the reduction in the scattering of this portion of the spectrum by gas molecules whose quantity per unit volume is reduced with increasing altitude. The ultraviolet radiation, exhibiting a wavelength from 200 to 290 mμ never reaches the ground, since it is absorbed by the ozone layer at an altitude of about 40 km.

Solar radiation is responsible for virtually all processes taking place within the terrestrial atmosphere, including changes in temperature with increasing altitude. In the troposphere (to an altitude of 9-11 km) the thermal equilibrium is basically regulated by the shifting and the state of the water vapors. From 11 to 32 km the temperature of the atmosphere is virtually constant (−56.5°C). Above 32 km, because of the absorption of radiative energy by the ozone, the temperature of the atmosphere rises and at an altitude of 50-55 km reaches +60° to +80°C. This temperature is retained to an altitude of about 65 km; then it drops to −30° at an altitude of 80 km, after which a continuous rise in temperature occurs as a result of the ionization of the air which is accompanied by the liberation of heat.

At an altitude of 200 km the temperature of the molecules reaches 400-500°C. However, because of the limited density of the air and the removal of heat as a result of radiation, in the upper layers of the atmosphere the temperature of a body at this altitude will be significantly lower.

The high ozone (O_3) content in the upper layers of the atmosphere represent a danger to human life. According to data from a number of investigations [16 and 21], the major portion of the ozone is found at an altitude of 15 to 35 km. Above 50 km there is virtually no ozone. The maximum concentration of ozone (by weight) is encountered at altitudes of 21-26 km where it reaches 0.0005 mg/liter. With an ozone concentration of 0.0002-0.001 mg/liter, we find irritation of the mucous membranes of the nose, throat, and eyes. Breathing air containing O_3 in quantities of 0.002-0.01 mg/liter for a period of 1 hour results in coughing, fatigue, headaches, and a burning sensation in the stomach. A concentration of 0.02 mg/liter results in pneumonia and irreversible pulmonary edema.

The maximum permissible concentration of ozone in the air for purposes of breathing is held to be 0.0001 mg/liter (BSE [Great Soviet Encyclopedia], Vol. 30, page 568).

If we take the atmospheric air at an altitude of 20 km where the ozone content on the average amounts to 0.02 cm/km,* and if this air is compressed to the cabin pressure which corresponds to an altitude of 8000 m, the ozone content (given a specific weight of 2 g/liter) will amount to about 0.0026 mg/liter, which is significantly in excess of the permissible norms.

Thus at altitudes of 20-30 km compressed atmospheric air cannot be used for human breathing purposes. The human being must be protected against the ozone or devices have to be developed to dissolve the ozone, changing it into oxygen (O_2).

In addition, let us take note of the fact that ozone is an extremely active oxidizer of all rubber products, significantly reducing their service life.

The cosmic rays moving in from interplanetary space continuously bombard the atmosphere, moving at velocities close to the speed of light. In the upper atmosphere, the earth is surrounded by an apparent halo of rapidly moving charged particles restrained by the terrestrial magnetic field.

Seventy nine percent (79%) of the primary cosmic rays consist of the atomic nuclei of hydrogen (protons) and twenty percent (20%) of the primary cosmic rays consist of helium nuclei (α-particles). The remaining (1%) of the primary cosmic rays is made up of heavy atomic nuclei (the composition and relationship between the various atomic nuclei in the cosmic radiation, apparently, corresponds to the relationship of these nuclei in the chemical composition of planets, stars, and meteorites).

The primary radiation reaches no closer than 50-25 km from the earth's surface. In this interval of altitudes the primary rays collide with the nuclei of atmospheric particles and form a multiplicity of secondary particles (secondary radiation), including electrons, neutrons, positrons, x-rays, etc. The intensity of the secondary radiation changes not only over altitude, but with respect to geographic latitude as well.

Because of their high speed and great energy (reaching billions of electron volts) cosmic rays easily penetrate matter, including the cells of living organisms, producing molecular ionization in these cells (ionization can also be used as a measure of cosmic-ray intensity). In the middle latitudes the intensity of the secondary cosmic radiation reaches its maximum and significantly exceeds its intensity at sea level (see Fig. 206).

§3. PRIMARY METHODS AND TECHNICAL FACILITIES FOR PROTECTING MAN AGAINST THE HARMFUL EFFECTS OF THE ATMOSPHERE AT HIGH ALTITUDES

The problem of physiological safety for high-altitude flights first of all reduces to the establishment of the required partial oxygen pressure in the inspired air. This can be achieved in two ways, i.e., by increasing the total pressure of the ambient air and by raising the percentage content of oxygen in the inspired air.

From the engineering standpoint, the safety of high-altitude flights is ensured by using: 1) hermetically sealed cabins; 2) aircraft oxygen equipment; 3) high-altitude G suits; 4) high-altitude space pressure suits.

In contemporary high-altitude aviation, as a rule, two methods of raising the partial O_2 pressure are employed simultaneously and they involve the combination of an airtight cabin, high-altitude equipment [clothing], and oxygen equipment.

This complex of equipment ensures flight safety and normal working conditions for man at any flight altitude, with minimum over-all weight of equipment aboard the aircraft.

Contemporary airtight cabins, ventilated by compressed atmospheric air, generally are employed for the over-all increase in pressure. The increase in the percentage content of oxygen in the inspired air is achieved by using individual oxygen units.

A pressurized cabin is the most radical means of protecting a human being against the harmful influence of high altitudes, including the harmful effects of pain in the joints, high-altitude meteorism, cold, etc. The idea of a hermetically sealed cabin was predicted as far back as 1872 by D.I. Mendeleyev.

At the present time all aircraft (with the exception of sport, training, and local transport aircraft) are fitted out with pressurized cabins in which climatized air is employed. However, the sudden depressurization of a cabin at great altitude as a result, for example, of a breaking window, the jettisoning of a canopy or hatch, leads to an instantaneous (in less than 0.5 second) drop in cabin pressure to that of the ambient air. This process is known as explosive decompression and may prove harmful or even fatal to the crew.

On the basis of research carried out by physiologists, it is thought that explosive decompression is harmless if the ratio

$$\frac{p_{k0}-47}{p_k-47}<3, \qquad (293)$$

where p_{k0} and p_k are, respectively, the pressure in the cabin prior to and after decompression, in mm Hg.

Generally p_k is equal to the atmospheric pressure p_H; however, if the loss in pressure is brought about by a break in the canopy pressurization hose, with aircraft in which the cockpit canopy rises above the fuselage we find that $p_k < p_H$ by a magnitude amounting to 20-35%

of the ram pressure as a result of the aerodynamic rarefaction in the canopy region. Therefore, in the subsequent discussion the phrase permissible altitude for utilization of oxygen equipment will be understood to refer to the "altitude" in the cabin [cockpit], determined by taking into consideration the possible expansion [rarefaction] (see the note on page 157).

In the case of cabin depressurization a conventional oxygen unit, even if pure oxygen is supplied, is inadequate to maintain flight above 12,000 m.

At high altitudes (above 14,000 m) explosive decompression leads to loss of consciousness and death, and only special high-altitude equipment [clothing] can serve as adequate protection. Therefore, in order to ensure flight safety and pilot survival in the case of a breakdown in cabin pressurization at high altitudes, G suits and high-altitude space pressure suits are employed. In a space pressure suit (just as in a pressurized cabin) equilibrium elevated air pressure acts on the body. The air circulates freely between the airtight shell and the surface of the body. In the case of a G suit, it is only the lungs and the entire head that are under elevated oxygen pressure. The balancing pressure against the body is achieved by the mechanical tensioning of the suit, tightly binding all parts of the body.

Figure 170 shows a G suit and a space pressure suit. The former is somewhat smaller in size than the space pressure suit.

When a pressurized cabin is functioning properly and the given excess air pressure (the "altitude" in the cabin, as a rule, does not exceed 8000 m) is maintained, the oxygen supply for the pilot passes through the helmet of the G or space-pressure suit from the corresponding oxygen equipment. In this case, both the shell of the G suit and the shell of the space-pressure suit exert no pressure against the

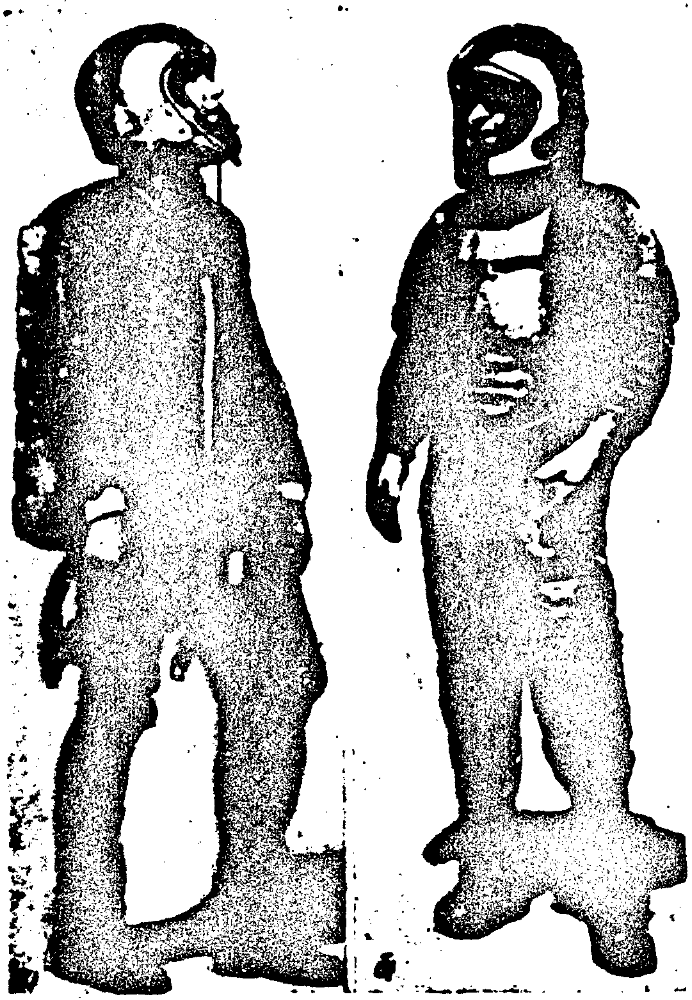


Fig. 170. Over-all view of contemporary G and space pressure suits. a) T-1 G suit (USA); b) high-altitude space pressure suit produced by the Goodrich Company.

body and represent virtually no restraint on the pilot's movement. If the pressurized cabin, however, should suddenly become depressurized [lose the excess air pressure], the automatic high-altitude equipment is immediately actuated and the pilot is supplied with oxygen at the absolute pressure required for the given flight altitude.

When the pilot wears a space pressure suit, the entire shell is automatically filled with air (it goes without saying of course that the visor of the helmet has an airtight seal).

If the pilot is using a G suit, then after a lapse of 0.5-1.5

seconds the chambers of the tensioning devices are filled with air, this being followed by elevation of the pressure in the helmet.

This sequence protects the lungs against mechanical damage as a result of uncompensated oxygen pressure.

It should be borne in mind that a space pressure suit not only ensures survival, but also makes it possible to continue flying without reducing altitude. A G suit is primarily a means of survival, since the staytime at great altitudes with a G suit having an airtight helmet ranges from several minutes to one hour, depending on flight altitude, the individual features of the organism, and the level of training.

The magnitude of the absolute air pressure both for the cabin and for the high-altitude equipment is selected on the basis of physiological requirements, the maximum flight altitude, considerations of strength, and minimum structural weight. In the case of passenger aircraft, in order to eliminate the need for oxygen in normal flight, the "altitude" in the cabin is maintained at no higher than 3000 m, which corresponds to an excess pressure of 0.47 kg/cm^2 at an altitude of 10,500 m. In the foreign literature we find the following maximum excess-pressure values and safe "altitudes" assumed [29, 34]:

– for pressurized bomber cabins, 0.4-0.45 kg/cm^2;

– for pressurized fighter cockpits, 0.25-0.3 kg/cm^2;

– for shells of high-altitude space pressure suits, 10,700-11,500 m;

– for airtight helmets of G suits, 12,000 m;

– for masks with excess pressure, used in conjunction with a G suit, 13,000 m.

From the standpoint of safety under conditions of explosive decompression, the safe "altitude" in a pressurized cabin in an aircraft (for any great flight altitude) is determined on the basis of Formula (293). Depending on the type of high-altitude equipment employed, this "altitude" should not, on the basis of calculation data which provide the basis for the above-cited excess-pressure data, fall lower than the following values:

for a mask with excess pressure............	7500 m
for a G suit with an airtight helmet.......	6300 m
for a space pressure suit with an "inside altitude" of 11,000 m....................	4800 m
for a space pressure suit with an "inside altitude" of 7500 m.....................	0 (i.e., ground pressure)

§4. OXYGEN-BREATHING EQUIPMENT

Aviation oxygen-breathing equipment is used to increase the percentage content of oxygen and its partial pressure in the inspired air.

As has already been pointed out, without the excess pressure the oxygen equipment can be used for flights up to an altitude of 12,000 m. In individual cases, an' for very brief periods of time, flight to an altitude of 13,000 m is possible.

Let us determine the oxygen content in the inspired air required to ensure the given partial oxygen pressure in the alveolar air. The partial pressure p_{O_2} of oxygen in the alveoli, as is well known, is equal to the total barometric pressure p_H minus the water-vapor tension (47 mm Hg), the partial carbon-dioxide pressure (p_{CO_2}), and minus the nitrogen in the lungs. Mathematically, this statement is written out as follows:

$$p_{O_2} = p_H - 47 - p_{CO_2} - \left[\frac{(p_H - 47)(100 - \xi_{O_2})}{100}\right], \qquad (294)$$

where ξ_{O_2} is the oxygen content in the inspired air.

The expression in the square brackets is the partial pressure of nitrogen in the alveoli, since the total nitrogen content (referred to dry air) is identical for both the inspired as well as for the alveolar air.

From Eq. (294) we obtain

$$t_{O_2} = \frac{p_{O_2} + p_{CO_2}}{p_H - 47} \cdot 100\%. \qquad (295)$$

The results obtained from the calculation of the oxygen contents required in a mask for p_{CO_2} = 40 mm Hg and p_{O_2} = 110 mm Hg, i.e., for the partial oxygen pressure in the alveoli, corresponding to ground conditions, are presented in Table 16.

TABLE 16

Required Oxygen Content in Mask, Corresponding to Ground Conditions

1 Высота полета в км	0	2	4	6	8	9	10
2 Содержание кислорода в маске в %	21	27	36	49	68	82	100

1) Flight altitude, in km; 2) oxygen content in mask, in %.

At an altitude of 10,000 m the breathing of pure oxygen is equivalent to the breathing of atmospheric air at sea level.

The oxygen equipment of an aircraft includes an oxygen supply, onboard and parachute oxygen equipment, an oxygen mask, connecting lines, monitoring instruments, hoses, and fittings. Here we will undertake a brief examination only of the actual oxygen-breathing devices, without which it would be difficult to understand the operation of the high-altitude equipment.

The oxygen equipment must satisfy the following primary requirements:

1) automatic control of percentage content of oxygen for [various] altitudes in accordance with a given law (see Table 16), both for slow

and rapid ascent;

2) minimum resistance to inspiration;

3) minimum oxygen flow rate;

4) operational simplicity;

5) failproof operation under conditions of aircraft vibration and within a temperature interval from -50° to $60^{\circ}C$ (the upper limit of the temperature requirements increases with each passing year as a result of the rise in aerodynamic heating and the difficulties encountered in cooling cabins).

In terms of operating principle oxygen equipment is divided into two basic types: 1) equipment with continuous supply of oxygen; 2) equipment with intermittent supply, i.e., the so-called automatic lungs.

In the case of the first type of equipment the oxygen is supplied in a continuous stream, whereas in the case of the automatic lungs it is supplied periodically, only during the inspiration phase. The automatic lungs are more economical in terms of oxygen flow rate, but they are generally inferior to the continuous-supply equipment in terms of dimensions and simplicity.

Inspiration backpressure is characterized by maximum rarefaction which a man creates in an oxygen mask in order to obtain inspired air of the required volume. It is desirable under all conditions for the inspiration backpressure not to exceed 15-20 mm water column. However, this requirement from the technical standpoint contradicts the requirement of minimum oxygen flow rate (for continuous-supply instruments) or leads to large valve and hose diameters in the case of automatic lungs.

With contemporary oxygen equipment the indicated magnitude of inspiration backpressure is achieved with lung ventilation of 7.5-15 liters per minute. With high lung ventilation (of the order of 30 liters per minute) the inspiration backpressure at sea level amounts to 60-70 mm water column. This makes it somewhat difficult to breathe and gradually tires the pilot. Figure 171 shows a typical relationship between inspiration backpressure and the magnitude of lung ventilation and flight altitude. With increasing altitude, as a result of the reduction in the gas density, inspiration backpressure diminishes and this is a favorable circumstance. It should be pointed out that of the over-all inspiration backpressure, the mask (the inspiration valve plus the corrugated hose with its seal) accounts for 55-70%, while the remainder is attributed to the on-board hoses, their connections, and the fittings. The inspiration backpressure of the actual oxygen equipment represents but an insignificant portion of the total backpressure, since the threshold of sensitivity for the automatic lung amounts only to 5-7 mm water column.

The inspiration backpressure is governed by the characteristic of the mask expiration valve, it is a function of the magnitude of lung ventilation, and in the case of average operation amounts to 30-40 mm water column. This backpressure also diminishes with increasing altitude.

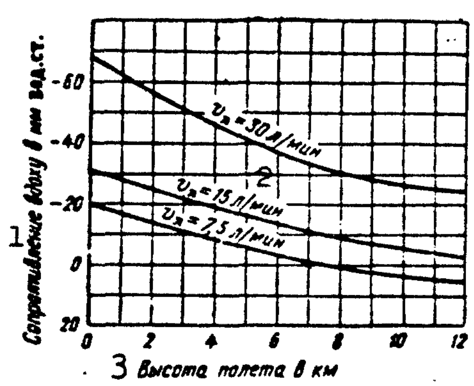


Fig. 171. Typical function relating inspiration backpressure with flight altitude and lung ventilation. 1) Inspiration backpressure, in mm water column; 2) liters per minute; 3) flight altitude, in km.

Let us determine the oxygen flow rate required by a device of the automatic-lung type, starting from the required percentage content of oxygen.

The oxygen concentration ξ_{O_2} in the inspired mixture is equal to the ratio of the entire oxygen volume to the overall volume of the mixture, equal to the

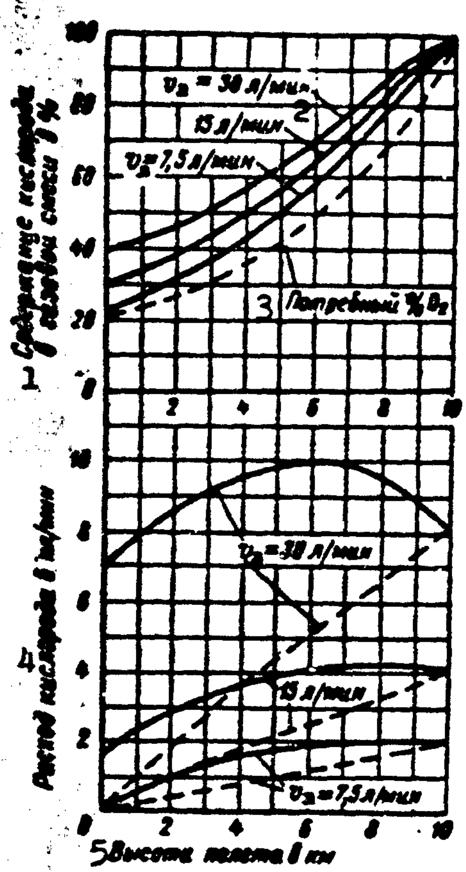


Fig. 172. Oxygen content in gas mixture and its flow rate as a function of flight altitude and lung ventilation. The dashed lines are theoretical. The solid lines represent average characteristics of contemporary equipment of the automatic-lung type. 1) Oxygen content in gas mixture, in %; 2) liters per minute; 3) required % of O_2; 4) oxygen flow rate, in standard liters per minute; 5) flight altitude, in km.

sum G_{O_2} of the oxygen supplied by the unit and the volume v_v of air drawn in:

$$\xi_{O_2} = \frac{G_{O_2}\frac{p_0}{p_H} + 0.21 v_v}{G_{O_2}\frac{p_0}{p_H} + v_v}, \qquad (296)$$

where p_0 and p_H are, respectively, the pressure of the atmospheric air at sea level and in the air. The volume of air drawn in by the equipment is equal to

$$v_v = v_l - G_{O_2}\frac{p_0}{p_H} \text{ l/min}, \qquad (297)$$

where v_l is the lung ventilation in l/min.

It follows from Expressions (296) and (297) that

$$G_{O_2} = v_l\left(\frac{\xi_{O_2} - 21}{79}\right)\frac{p_H}{p_0} \text{ standard liter/min.} \qquad (298)$$

The results of the calculation carried out in accordance with Formula (298) are presented in the form of dashed lines in the lower half of Fig. 172. The solid lines in this same figure show typical characteristics of contemporary oxygen equipment operating in the form of an automatic lung. The oxygen flow rate is somewhat higher in an actual piece of equipment than on the basis of theoretical calculation. This is explained by the fact that the exact maintenance of a given oxygen content in the gas mixture is difficult to achieve from a technical standpoint and contemporary units yield an elevated percentage of oxygen in the mixture, particularly in the case of high lung ventilation (see the solid lines in the upper part of Fig. 172). Thus in principle it is possible to achieve a further increase in the economy of oxygen equipment.

The oxygen flow rate in the case of a continuous-feed apparatus is associated with the design of the oxygen mask and the breathing system.

The initial oxygen equipment was of the continuous-feed type, the mask being open. In these devices, the oxygen was supplied from a tank through a pressure reduction valve and a metering mechanism to the mask which had been provided with a calibrated orifice opening out to the air. On expiration the oxygen was uselessly expended, while during inspiration atmospheric air was drawn in and the oxygen content in the inspired air was reduced. The high-altitude capabilities of this equipment on the average amounted to 8 km and did not exceed 10 km (without physical exertion). Among these pieces of equipment we should, in particular, include the KPA-3bis which proved itself so useful during the Second World War. With the O_2 emergency supply valve open (i.e., at the expense of a pronounced increase in the oxygen flow rate) it was possible to execute flights to 12 km and higher with this device.

In order to reduce the oxygen flow rate and to increase its content in the inspired air, additional containers are incorporated into the continuous-feed equipment complex, and this container fills with oxygen during the expiration phase. During inspiration, this oxygen volume is connected to the continuous-feed mechanism of the unit. Structurally, the additional container is made in the form of a sack on the mask or in the form of a rubber bag held in a rigid container (the so-called economizer), installed aboard the aircraft directly into the inspiration-hose line.

Table 17 shows the oxygen flow rates for a single human being when using a continuous-feed unit for an open-type mask and a mask with an additional container.

TABLE 17

Oxygen Flow-Rate Norms for a Single Individual Using Continuous-Feed Equipment

1 Высота полета *км*	0	2	3	4	6	8	10	12
2 Расход кислорода прибором КП-22 с маской открытого типа в *л/мин*	0	0—2	1—3	2—4	3,5—6	6—7	4 Прибор не применяется	
3 Расход кислорода прибором КП-32 с маской с мешочком в *л/мин*	0	0	0—2	1—3	2—4,5	3—5,5	4—6,5	4,5—7

1) Flight altitude, in km; 2) oxygen flow rate with KP-22 equipment, using open-type mask, in standard liters per minute; 3) oxygen flow rate with KP-32 equipment, using container mask, in standard liters per minute; 4) no equipment employed.

Oxygen Masks

An oxygen mask must exhibit the following properties:

1) it must simultaneously cover nose and mouth, and it must present no difficulty in breathing;

2) it must fit tightly against the face and should not move even under great stress;

3) it should not shift on the face nor should it come loose when subjected to ram pressure during ejection from the cabin;

4) it must maintain the excess pressure (for masks with elevated pressure);

5) it should not inhibit speech and communications by means of a radiotelephone;

6) it should not impair visibility nor should it restrict the movement of the head;

7) the donning and fastening of the mask must be rapid, convenient,

and reliable, and its removal must be easy and fast;

8) prolonged wearing of the mask should produce no pain as a result of mask pressure nor should it result in any irritation of the facial skin;

9) the mask valve (inlet and outlet) must function perfectly, exhibit little backpressure, be airtight, and should not freeze over in the case of low ambient-air temperatures (in contemporary aircraft, because of cabin air conditioning, the requirement as to anti-icing devices retains significance only in the case of a crash or parachute descent);

10) the materials used for the fabrication of masks and hoses should be free of odor.

The airtightness of the mask is a primary prerequisite if the required oxygen content in the inspired air is to be obtained.

Many of the catastrophes occurring at great altitudes, their causes as yet unexplained, were probably the result of loss of consciousness on the part of the pilots as a result of oxygen starvation. This assumption is confirmed by the following fact.*

Several USAF units conducted flight tests of oxygen equipment. The flights were conducted with aircraft whose cabins were pressurized and with dual controls. Unbeknown to the operating pilot, the inspector pilot opened the air-pressure cock of the cabin prior to the take-off. The aircraft was then taken up to an altitude of 9150 m and remained at this altitude for 30 minutes. During this period 10.5% of the flight crew being tested experienced oxygen starvation, including 7% who fainted for brief periods of time. This was attributed primarily to the lack of attention devoted to the care and maintenance of oxygen-mask cleanliness, as a result of which the expiration valve was not airtight. In other cases, the mask proved to be hermetically inadequate because of improper size selection and inattention to its testing prior to application and its fit on the face.

Contemporary pilot masks are generally made in several dimensions in order to provide more uniform fitting of the mask to the face and to ensure good airtightness for various anthropological types and head dimensions. The airtightness of the mask is characterized by the magnitude of suction air, and this must be kept to a minimum.

The transmission of speech over a radiotelephone may be carried out by means of conventional throat mikes or by means of a microphone mounted directly inside the mask. The microphone yields better speech clarity under high-altitude conditions. The microphone should also be preferred because the pilot will not take off from an airfield without requesting permission by radio and, consequently, it is impossible for him to take off without his oxygen mask.

In order to reduce the forces acting on the mask in the case of acceleration, its weight should be kept to the minimum. Moreover, a light mask exerts less pressure against the face. In order to prevent the shifting of the mask in the case of ejection and exposure to the airstream, appropriate fastening devices are employed and the mask is fashioned in proper configuration of frame. The upper center strap prevents downward movement. Movement upward and to the sides is, in addition to the side strap, blocked by the lower portion of the mask surrounding the chin.

No special requirements associated with ejection or exposure to the airstream are imposed on masks and oxygen equipment intended for passenger aircraft. For these, the most important requirement is economy of oxygen flow rate and simplicity of mask handling. Figure 173 shows a diagram of a domestic oxygen mask (KM-19) with an additional container, used in conjunction with the KP-32 oxygen equipment designed for multiple use (20 people) aboard passenger aircraft.

The KM-19 mask operates in the following manner.

The oxygen is supplied in a continuous stream through a thin hose 7 and a perforated tube 6 to the breathing (rubber) sack 5. The latter is connected by means of a wide connection tube 4 to the frame of the mask 1.

On expiration the first portion of air, which is richer in oxygen, fills sack 5; all of the residual expired air, saturated with carbon dioxide, is passed out through two porous valves 3. At the instant of inspiration the subject draws in all of the oxygen carried in the sack in addition to the oxygen supplied in the continuous stream. Thus the sack reduces the inspiration backpressure and makes it possible to reduce the oxygen flow-rate norm (see Table 17).

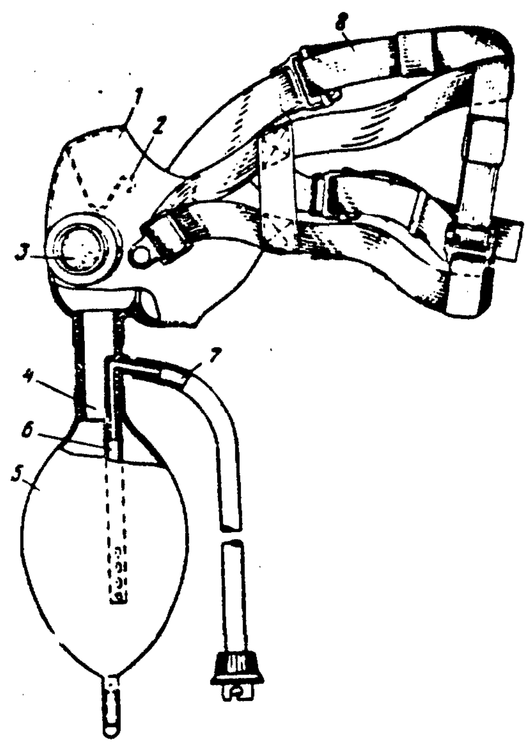


Fig. 173. KM-19 oxygen mask with additional container. 1) Mask frame; 2) wire support; 3) expiration valve; 4) connection tube; 5) breathing sack; 6) tube; 7) oxygen supply hose; 8) fastening strap.

The wire support 2 is used to fit the frame of the mask onto the

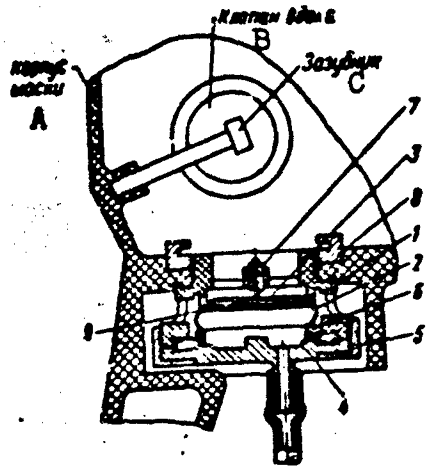


Fig. 174. Mask expiration valve with excess pressure. 1) Expiration valve frame; 2) valve membrane; 3) iris valve; 4) cover plate; 5) connector nut; 6) annular shock absorber; 7) guide sleeve; 8) nut; 9) spring. A) Mask frame; B) inlet valve; C) bit.

bridge of the nose, and straps 8 are employed to fasten the mask to the head.

In contemporary passenger aircraft the possibility of donning masks rapidly is achieved by the fact that in the case of a drop in cabin pressure the mask is automatically released from its container in the ceiling of the cabin, and it dangles by its hose in front of the passenger's face.

A schematic diagram of an excess-pressure mask together with the oxygen unit is shown in Fig. 176.

The over-all view of the mask used in conjunction with a G suit is shown together with the protective helmet (see Fig. 208). The frame of the mask consists of a single piece of rubber with a soft bead to ensure tight application against the face. A shaped steel clamp in the frame is used to hold the fastening straps of the mask. The clamp, moreover, protects the mask against deformation as a result of the forces of the internal excess pressure or as a result of the outside airstream.

A schematic diagram of the mask's outlet valve, functioning under excess pressure, is shown in Fig. 174. The oxygen enters the mask during the inspiration phase through a corrugated hose and the inlet valve. The latter consists of a rubber plate valve and a plastic seat.

The outlet valve is intended to eliminate the exhaled gaseous mixture, whether or not excess pressure exists in the mask. The iris outlet valve 3 is therefore compressed by spring 9 to its seat by the rubber valve membrane 2 whose internal cavity is connected by a tube to the inspiration line or to the mask-pressure regulator. When oxygen under excess pressure enters the mask at altitudes in excess of 12 km, the same pressure acts on the inside of the valve membrane 2, balances the pressure in the mask, and the valve cannot open on its own. The valve will be sealed even more tightly during inspiration, as the pressure inside the mask is reduced. On expiration, the pressure in the mask rises, the iris valve 3 and the valve membrane 2 back off from the seat, and the expired mixture passes into the atmosphere through the orifices in the valve frame. Spring 9 ensures the airtightness of valve 3 on inspiration and eliminates the possibility of its adhering to the valve membrane.

In order to ensure a tighter fit of the mask against the face, a tension compensator is fastened to the headset of the helmet. As excess pressure is built up in the mask, the rubber chambers of the compensator fill with air and extend the mask-fastening straps.

The oxygen masks employed with automatic lungs for flights below 12,000 m differ from those described in that they have a simple outlet valve consisting of a thin mica disk pressed against the plastic seat by means of a spring.

Contemporary masks exhibit the following weights:

Mask for flights below 12,000 m.......	0.35-0.5 kg
Mask with excess pressure (including pressure regulator and tension compensator).......................	1.2 -1.7 kg

To prevent the weight of the regulator and the hoses from exerting pressure against the pilot's head, the regulator is fastened to the strap of the parachute suspension system by means of a fast-acting release.

Masks for space pressure suits are similar to masks employed below altitudes of 12,000 m, but they are lighter in weight, since they are not called upon to resist the airstream. In order to reduce the dimensions of masks worn underneath a helmet, the inlet and outlet valves are sometimes removed from the masks and positioned along the appropriate hoses.

Particular attention should be devoted to the problem of the taking in of food and water by a pilot wearing an oxygen mask. According to literature data* the pilot of a strategic aircraft loses about 7 kg in weight as a result of evaporation during a period of 8-9 hours, even if he is sitting still. In order to retain mental and physical operational efficiency, the pilot must be able to consume water and food. The brief removal of the mask can be tolerated if the "altitude in the cabin" is not in excess of 6000 m. To feed a pilot at great altitudes, use is made of masks in whose front sections at mouth level a special airtight valve has been installed. This valve can be forced open by means of the plastic mouthpiece which can be connected, by means of a tube, to a thermos containing tea, coffee, milk, water, or nutritional liquid mixtures.

On-Board (Stationary) Oxygen Equipment

The basic and most common type of on-board oxygen equipment is the one involving intermittent feed. It should be pointed out that in its pure form the principle of the automatic lung, i.e., supply according to need during the inspiration phase, is suitable only as long as the "altitude" in the cabin does not exceed 12,000 m and the oxygen mask fits tightly against the face. In the remaining cases, the on-board equipment, through use of additional mechanisms, provides for a continuous supply of oxygen. This improves the reliability of oxygen supply and ensures safety in high-altitude flight.

A typical schematic diagram of an oxygen unit, of the automatic-lung type, is shown in Fig. 175.

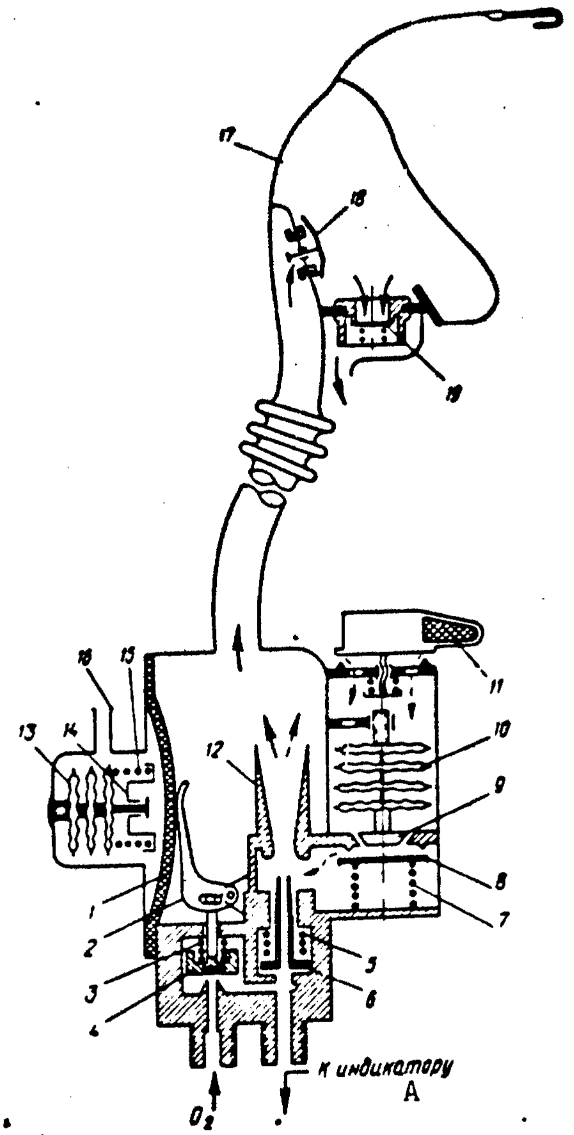


Fig. 175. Schematic diagram of automatic-lung oxygen equipment. 1) Membrane; 2) lever; 3, 5, 7, 15) springs; 4) valve; 6) injector nozzle; 8) reverse valve; 9) air intake valve; 10) diaphragm box; 11) manual air-intake switch; 12) injector diffuser; 13) diaphragm box of excess-pressure mechanism; 14) cap; 16) connection tube (communicates with the atmosphere or connects to the shell of the space pressure suit); 17) oxygen mask; 18) inlet valve (rubber); 19) outlet valve (mica). A) To indicator.

The device functions in the following manner. The expansion in the mask on inspiration propagates along the hose to the frame of the unit, the elastic membrane 1 bends and presses against lever 2 of the automatic lung. Lever 2 opens valve 4 through the transmission links and the oxygen passes to the nozzle of injector 6 and simultaneously to the connection tube of the indicator. The stream of oxygen emanating from nozzle 6 produces rarefaction in the housing of the injector and through the return valve 8 draws in air from the outside, forming an oxygen-air mixture. The composition of the mixture is controlled automatically by valve 9 which communicates with the diaphragm box 10. With increasing altitude the diaphragms expand and reduce the flow-through cross-sectional area open to the air. At an altitude of about 9000 m valve 9 is completely closed off and pure oxygen enters the mask.

The pilot can set off the air intake at will by turning lever 11. This may become necessary in the case of desaturation or upon the appearance of harmful impurities in the cabin.

On expiration the pressure in the operating chamber of the device increases, membrane 1 and lever 2 deflect to the left (of the figure), valve 4 closes, and the supply of oxygen is shut off until the subsequent inspiration.

The nozzle of the injector has an extremely small orifice and may easily become fouled. In order to prevent the stoppage of the oxygen supply and to prevent the breakdown of the indicator, the nozzle is fabricated in the form of a safety valve which is closed by means of spring 5.

The nozzle functions as a valve as well when the required oxygen volume exceeds the flowthrough capacity of the nozzle itself.

In order to reduce the danger of oxygen starvation as a result of an improperly fitted mask, the device is equipped with an additional mechanism consisting of diaphragms 13, cap 14, and spring 15. At altitudes in excess of 5-6 km, the diaphragms expand and begin to press against the membrane through the cap 14 and spring 15. If the mask is airtight and a pressure of 35-40 mm water column is maintained in the mask on expiration, the force of the internal pressure against the membrane exceeds the force of the spring 15 and during the expiration phase valve 4 will be closed. If, however, the mask is not properly fitted, the unit will feed oxygen continuously, both during the inspiration and expiration phases, which is easily detectable from the readings of the oxygen indicator.

The on-board oxygen equipment intended for flights to altitudes below 12,000 m is fabricated in accordance with this description.

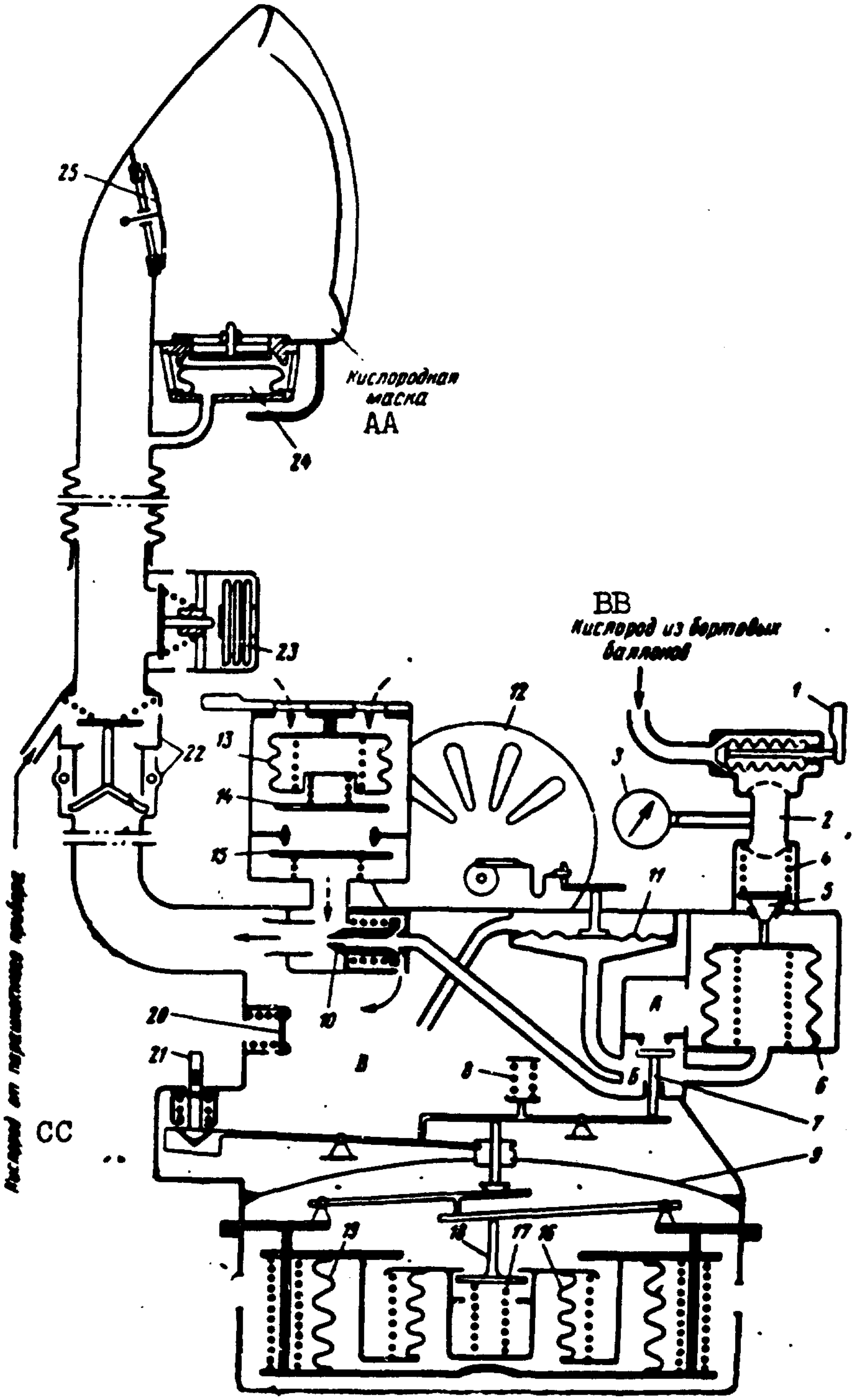
In order to provide the required partial oxygen pressure in the case of flights at higher altitudes, it is necessary to generate excess oxygen pressure in the lungs.

Without balancing counterpressure against the chest and abdominal cavities, the excess pressure in the mask cannot be permitted to exceed 400 mm water column, and this will make possible operations at altitudes up to 15 km for as long a period of time as is required to bring the aircraft back to the safe altitude of 12 km.

In order to fly at altitudes below 15 km, the absolute pressure in the mask must correspond to an altitude of no more than 13,000 m, and the entire surface of the body must be subjected to a counterpressure equal to the pressure difference between an altitude of 13,000 m and the actual flight altitude. If this is not achieved, expiration becomes intolerably difficult, and the blood circulation is disrupted as a result of the concentration of blood from the body at the extremities.

As an example of a piece of oxygen equipment fitted out with a high-pressure mechanism, we present below a description of the British Mk-17 device which is similar to the American D-2 unit (Fig. 176).

The device is equipped with a pressure-reduction mechanism which reduces the oxygen pressure on inspiration from 30 or 14 kg/cm^2 to 2.1 kg/cm^2, and there is also an automatic air-intake mechanism that is



ig. 176. Diagram of excess-pressure oxygen unit. 1) Stopcock; 2) fil-
er; 3) manometer; 4) spring; 5) inlet pressure-reducer valve; 6)
ressure-reducer bellows; 7) automatic-lung valve; 8) automatic-lung
pring; 9) automatic-lung membrane; 10) injector nozzle; 11) flow-
ndicator membrane; 12) "flashing light" of indicator; 13) bellows for
utomatic air intake; 14) valve of automatic air intake; 15) return-
low valve; 16) low excess-pressure bellows; 17) spring; 18) plunger;
)) high-pressure bellows; 20) safety valve; 21) manual excess-pressure
vitch; 22) fast-release sleeve; 23) pressure regulator for mask; 24)
ompensation valve, expiration; 25) inspiration valve. AA) Oxygen mask;
3) oxygen from on-board tank; CC) oxygen from parachute unit.

similar to the one described above (see Fig. 175).

The operating principle of the pressure-reduction mechanism and the automatic-lung mechanism becomes clear from the diagram.

At an "altitude" in the cabin ranging from 0 to 3 km, the oxygen or air-oxygen mixture, enters from cavity C [B] of the automatic lung into the mask at a pressure equal to the air pressure in the cabin. When the "altitude" in the cabin reaches a level of 3 km, the low excess-pressure bellows 16 begins to expand and the central spring 17, which is tensioned, releases and through plunger 18 and the system of levers acts to open the automatic-lung valve.

The forces exerted by springs 8 and 17, the area of the large membrane, and the gear ratios of the levers are chosen so that at an altitude of 3.6 km a pressure of 25 mm water column is developed in the operating cavity of the device. This pressure prevents the drawing of air into the mask from the surrounding air and facilitates inspiration.

If the "altitude" in the cabin rises above 12 km, the high-pressure bellows 19 expand, as a result of which the central spring 17 becomes more tensioned and the force applied to the center of the automatic-lung membrane increases as the pressure drops in the cabin, thus opening valve 7 slightly. As a result the oxygen is supplied for purposes of inspiration under excess pressure in comparison with the ambient medium. In the case of the Mk-17 unit the excess pressure changes from 50 mm water column at an altitude of 12 km to 410 mm water column at a cabin "altitude" of 15 km.

The return-flow valve 15 in the automatic air intake prevents leakage of oxygen when the pressure in the operating cavity C [B] is greater than the air pressure in the cabin.

The safety valve 20 installed in the frame of the device prevents a rise in pressure in the operating cavity of the unit above 1000 mm water column.

Emergency key 21 which communicates with the levers of the automatic lung through a spring is operated to check the excess pressure in the mask prior to takeoff. The key has two positions, i.e., in the first position (turning of the key) an excess pressure of 50 mm water column is developed while in the second position (pressure against the key) the excess pressure amounts to 254 mm water column.

In the event of ejection, the oxygen supply from the parachute unit is connected and a fast-release sleeve is actuated, subsequent to which the excess pressure in the mask is maintained by means of the regulator installed at the end of the mask hose.

In addition to the described direct (mechanical) method of developing excess pressure in the oxygen equipment, we also make use of pneumatic control. In this case, a small additional quantity of oxygen is fed into the cavity above the membrane and the pressure in this cavity is regulated in accordance with the altitude by means of the diaphragm and the springs of the safety valve. This pressure produces the same effect as the direct action of the bellows and springs against the membrane of the automatic lung.

In the case of devices with excess pressure the magnitude of the continuous oxygen supply actuated automatically at an altitude of 11,500-12,500 m generally amounts to 15-20 liters per minute (referred to ground conditions). The shutting off the supply may occur with a certain lag at an altitude of about 8 km. We shall have to bear this in mind in calculating the required oxygen supply.

<u>Monitoring Instruments</u>

The monitoring and control of proper operation of the on-board oxygen equipment is achieved by means of manometers and so-called oxygen-flow indicators. In the case of equipment with continuous oxygen feed the operational principle of the indicator is analogous to a floating rotameter (gas flowmeter) or it is based on the principle of measuring the pressure difference across the narrow and wide sections of a Venturi tube. In the case of automatic lungs high-quality flow indicators made in the form of two blinking "eyes" (tabs) are installed, these reacting to a change in pressure at the instant of inspiration at the inlet to the automatic-lung injector. In the case of continuous oxygen feed the eyes of the indicator remain open throughout.

To monitor the pressure in space pressure suits and the helmets of G suits a combined device is employed, i.e., the so-called altitude and pressure-difference indicator. The main scale of the instrument indicates the altitude to which the pressure in the helmet (mask) corresponds. Moreover, the instrument measures the pressure difference between the helmet and the cabin.

Parachute Oxygen Equipment

General information, requirements, and operating principle

Parachute oxygen equipment (PKP) consists of elements for individual use and supplies pilots with oxygen in the case of aircraft ejection and parachute descent. Moreover, PKP may be employed in the event that the main oxygen system breaks down, and it may also be used to supply oxygen during the descent of an aircraft to a safe altitude (i.e., an altitude of the order of 4000 m, beneath which oxygen is no longer required).

In terms of operational principle PKP is included among the continuous-feed oxygen equipment. The oxygen supply is kept under high pressure (150 atm) in a group of tanks or in a single bottle. Under normal flight conditions this supply is not consumed and the pilot breathes the oxygen supplied by the on-board equipment.

The basic requirements imposed on PKP can be reduced to the following:

1. In the case of ejection from the aircraft the actuation of the oxygen supply must proceed automatically, with absolute reliability, and without fail.

2. In the assembly of the equipment it is necessary to take into consideration the manner in which it is carried by the individual and the way it is stored in the parachute. The equipment should not interfere with the pilot's ability to fly nor should it hinder the ejection procedure.

3. The oxygen supply norms and the oxygen reserve norms must be matched to the regime and time of descent during the pilot- and main-chute phases.

The physiological norms of oxygen supply to the mask from the parachute equipment may be determined on the basis of the data presented in Table 18.

TABLE 18
Physiological Norms of PKP Oxygen Supply

1 Высота в км	2 12 и выше	11	10	9	8	7	6	5
3 Норма подачи O_2 в л/мин не менее	14	12	9,5	7,5	6	4	3	2

1) Altitude, in km; 2) 12 and higher; 3) O_2 supply norm, in standard liters per minute, not less than.

In terms of the method employed to regulate the supply of oxygen, parachute equipment can be divided into equipment having pressure-reducing apparatus and equipment having no such device. In the equipment with pressure-reducing apparatus, the pressure of the oxygen entering from the bottle drops from 150 to 4-10 atm (varying with the

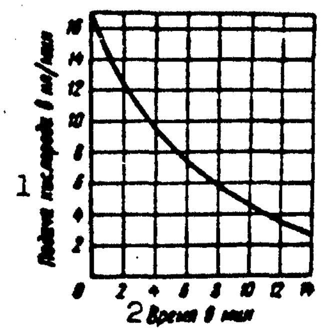


Fig. 177. Oxygen flow rate as a function of KP-23 operating time. Capacity 0.83 liter; initial pressure, 150 atm. 1) Oxygen supply, in standard liters per minute; 2) time, in minutes.

manufacturer). At the outlet from the pressure-reduction apparatus there is a jet (nozzle). The adiabatic discharge of the oxygen through the nozzle at sonic critical speed and with constant pressure in front of the nozzle provides for a constant oxygen flow rate in this type of equipment. This flow rate is generally set to range from 6 to 8 standard liters per minute. This equipment is used for flights with masks to altitudes of the order of 10 km.

In the case of parachute KP in which there is no pressure-reduction equipment, the oxygen is discharged from a bottle directly through a nozzle or capillary tube and then enters the inspiration hose of the mask. In either case, the oxygen flow rate is greatest at the instant at which the equipment is turned on and it diminishes as the pressure drops off in the tank (bottle) (Fig. 177). This type of characteristic is for the most part in correspondence with the required physiological norms (see Table 18) and the regime of descent.

In the case of equipment without pressure-reducing apparatus and where the diameter of the nozzle is extremely small (less than 0.15 mm), fabrication of the equipment is difficult. Copper tubes with an inside diameter of 0.35 mm and 4500 mm long are used in the equipment using capillary tubes. The required oxygen flow rate is achieved by calibration of the inside channel of the tube with chemical etching. The indicated tube diameter and the length of the tube are selected so as to eliminate the possibility of the freezing in the tube of the moisture which may be contained in negligible quantities in the oxygen. In equipment employing a nozzle freezing is more likely, since the process of adiabatic discharge from the nozzle is accompanied by a significant reduction in temperature.

When the separation of the pilot from the ejection seat is calculated for altitudes of 5 km or lower, it is possible to use parachute oxygen equipment that is stored together with the oxygen supply in the seat. This equipment may be either of the continuous-feed or automatic-lung variety.

At the present time the most common equipment in use is the parachute oxygen equipment without any pressure-reduction apparatus, this equipment carried either by the pilot or as part of the parachute suspension system.

Assembly and design of parachute oxygen equipment and its functioning on ejection

Parachute KP is assembled either with a single bottle or with a group of tanks mounted in a flat container.

The first assembly version is the type used in British-American equipment. The following devices are mounted at the throat of the bottle which has a water capacity of 0.4-0.7 liter: a stopcock, a small-scale manometer, a metering nozzle with a filter in front, and flow and charging connection tubes. Parachute equipment of this type is stored in a soft covering case which is strapped to the suspension system of the parachute at belt height or directly to the pilot's hip (see Fig. 170a). The bottle must be fastened securely to prevent its being torn away on ejection.

The automatic switching on of the equipment is carried out by means of a barometric sensing element at a pressure corresponding to an altitude of about 13,000 m. Provision is also made for manual operation of the equipment (see the sphere with a cable in Fig. 170a).

The second assembly version is employed for domestic parachute equipment, i.e., KP-23 and KP-27M. The schematic diagrams of these two types of equipment are shown in Fig. 178. The oxygen is carried in a grouping of series-connected German-silver bottles with a total capacity of about 0.83 liter with an outside diameter of 20.5 mm and a wall thickness of 1.25 mm. The operating pressure is 150 atm. All of the equipment is mounted in a 23-mm-high duralumin box which is fastened to the pack of a "seat" parachute or (in the case of a parachute backpack) to the suspension system.

A charging connection tube 1 is connected on one side of the bottle group, while manometer 5 and capillary tube 6 are connected to the other side (the parameters of the capillary tube were presented earlier). The bottle grouping is connected through the capillary tube to the stopcock device. The actuation of the equipment is carried out automatically on ejection.

The KP-23 and KP-27M equipment shows a number of structural differences, primarily in the stopcock system (the switches). These differences are based on the fact that the first unit is employed with seats that have not been provided with consolidated tubing releases, while the second piece of equipment is designed to function in combination with a VKK [high-altitude G suit] designed for seats equipped with such consolidated releases. Figure 178 shows how parachute oxygen equipment is connected.

In the case of the KP-23 unit the oxygen hose connecting the on-board equipment to the oxygen mask passes through a switch equipped with a stop valve and a fast-acting release (Fig. 179). At the instant that the pilot leaves the aircraft the disconnecting of the on-board hose and the switching to the [oxygen] supply from the parachute equipment are carried out simultaneously and automatically. With the initial movement of the seat the halyard 16 (a chain or cable) tenses, the

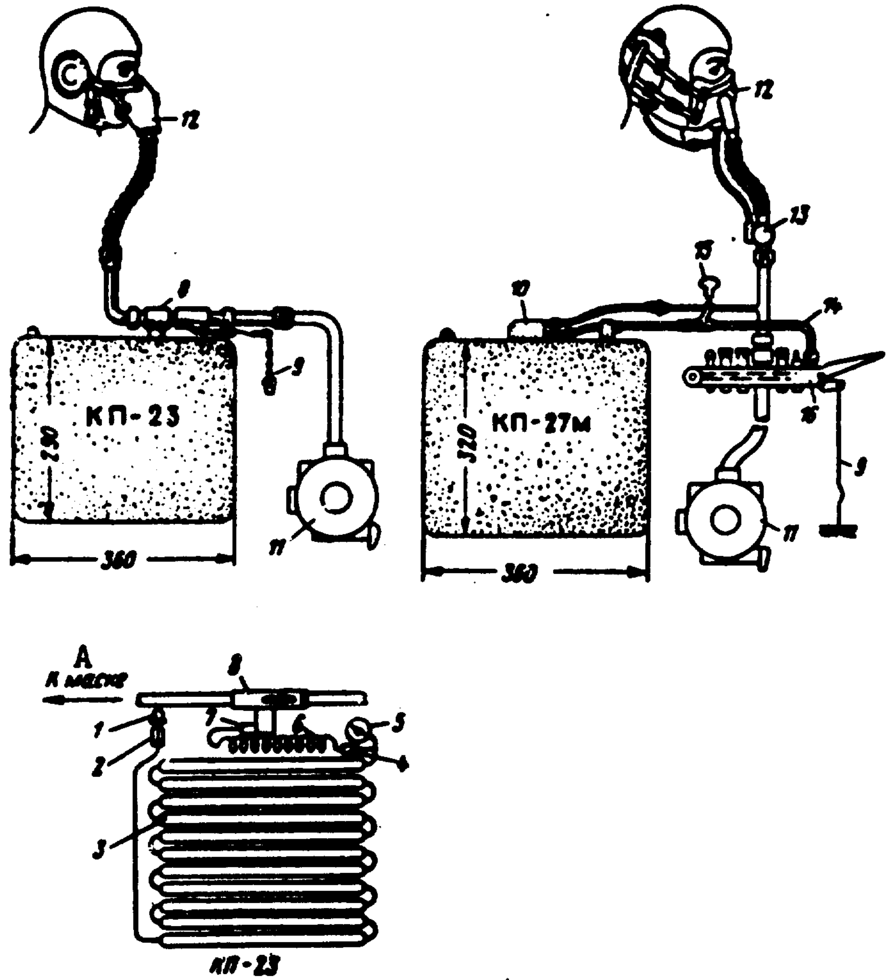


Fig. 178. Schematic diagram of KP-23 and KP-27M parachute oxygen equipment. 1) Charging connection tube; 2) return-flow valve; 3) bottle group; 4) filter; 5) manometer; 6) capillary tube; 7) stopcock; 8) switch; 9) halyard (chain or cable); 10) starter; 11) on-board (stationary) oxygen equipment; 12) mask; 13) pressure-reducing mechanism in mask; 14) Bowden cable guide through which passes the cable release for the KP-27M equipment; 15) manual switch; 16) consolidated release. A) To the mask.

pins of the release 14 are jerked out of their openings, the plate springs 12 release the conic projections 11 of the switch and under the action of spring 5, lever 6, and rod 10 the hose of the on-board equipment is jettisoned. Simultaneously, spring 5 presses against plunger 4, opens the stopcock 3, and the oxygen streams out of the bottles through the capillary tube into the mask hose. The return-flow valve 9 blocks oxygen leakage from the frame of the switch to the atmosphere. As the oxygen reserve is used up and the oxygen supply is reduced, at which time expansion may take place in the mask on inspiration, the air required for breathing is drawn in through the mica valve 9.

The airtightness of the oxygen hose connecting the two parts of the switch is ensured by means of a rubber pad 13 which is kept under

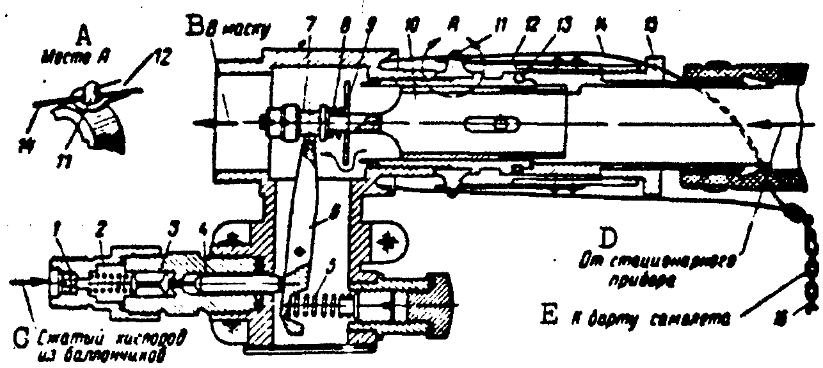


Fig. 179. KP-23 equipment switch. 1) Filter; 2, 5, 8) springs; 3) stopcock; 4) plunger; 6) lever; 7) dog; 9) return-flow valve; 10) rod; 11) insert with conic projection; 12) spring; 13) rubber pad; 14) release pin; 15) screw-sleeve; 16) release chain (halyard). A) Position A; B) to mask; C) compressed oxygen from bottles; D) from stationary equipment; E) to aircraft.

pressure by means of a screw-sleeve 15 after pins 14 have been inserted into cones 11.

Unlike the KP-23 equipment, the parachute KP-27M equipment lacks a release for the separation of the on-board oxygen hose (the latter passes to the side of the equipment), and there is only a starter [trigger] for the automatic or manual actuation of the oxygen feed. The separation of the on-board hoses is achieved by means of a special mechanism known as a consolidated tubing release that is attached to the seat. On ejection of the pilot the consolidated release opens automatically by means of a halyard that is fastened to the cabin floor. When this takes place the lower section of the release which is connected to the cable (which actuates the KP-27M equipment) is attached remains in the aircraft, while the upper portion of the release "moves away" together with the pilot. The return-flow valve in the connection tubes of the upper section [of the release] close off all of the plumbing, insulating the breathing organs from the atmosphere. The oxygen-supply hose from the KP-27M equipment to the mask and the G suit are connected directly to the appropriate plumbing by means of a T-joint at a point between the upper portion of the consolidated release and the individual equipment (see Fig. 188).

The trigger of the KP-27M equipment (Fig. 180) functions in the following manner, i.e., when cable 14 is jerked out key 13 is pulled out of pin 12. As a result rod 10, fastened by means of lever 11 to pin 12 presses against plungers 6 and 4 under the action of the tensioned spring 9. Plunger 4 opens the stopcock 3. As it continues to move rod 10 presses pad 7 which it carries against bracket 8, thus securing the airtightness of cavity A. The drawing in of the air required with the reduction in the oxygen supply is achieved by means of the mica valve in the oxygen connection tube of the inspiration line in the upper section of the consolidated release.

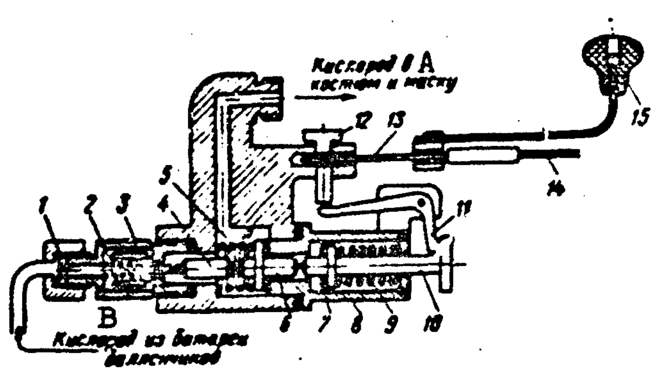


Fig. 180. Schematic diagram of KP-27M trigger. 1) Filter; 2, 5, 9) springs; 3) valve; 4, 6) plungers; 7) pad; 8) bracket; 10) rod; 11) lever; 12) pin; 13) key; 14) cable attached to the on-board section of the consolidated release; 15) manual actuator. A) Oxygen to suit and mask; B) oxygen from bottle group.

The weight of the parachute oxygen equipment is as follows: KP-23, 4.9 kg; KP-27M, 5.3 kg.

Storage of parachute KP-23 and KP-27M equipment with parachute and in seat

Parachute oxygen equipment of the KP-23 and KP-27M variety are used together with parachutes whose backpacks are equipped with a special pocket to carry the parachute oxygen equipment. In flights in which the portable emergency kit is carried in the bucket of the seat, the pocket for the parachute [oxygen] equipment is positioned between the emergency kit and the pilot, fastened to the parachute suspension system.

As a rule, KP-23 and KP-27M equipment is carried in a pocket on the front side of the parachute, i.e., the trigger for the equipment facing the same direction as the pilot. However, an opposite position for the equipment is possible. If the KP-23 equipment is stored so that the hoses face in the direction of the seat backrest, a sufficiently large opening must be provided for in the bucket of the seat to provide an exit for the separating hose during ejection and this must be tested by operating the ejection mechanism in a ground installation.

The KP-27M equipment must be positioned so that the hose is directed toward the consolidated plumbing release. For aircraft from which ejection proceeds upward, the consolidated release is generally mounted on the left-hand side of the seat.

§5. HIGH-ALTITUDE G SUITS (VKK)

General Information and Operating Principle

VKK [G suits] are used to ensure flight safety and pilot survival in the case of cabin depressurization at altitudes in excess of 12-15 km. G suits are used either in conjunction with an oxygen mask under excess pressure or in combination with an airtight helmet (see Fig. 170a).

In the first case the maximum flight altitude is 16-17 km, while in the latter case it is possible to operate at a flight altitude of 40-50 km, although for only a very limited period of time involving but a few minutes.*

At altitudes below 12 km the absolute oxygen pressure in the hermetically sealed helmet is equal to the ambient pressure. Above 12 km, a constant absolute pressure is automatically maintained in the airtight helmet, this pressure corresponding to the altitude in question, i.e., 144 mm Hg. Therefore, when climbing to an altitude above 12 km we find the excess pressure in the airtight helmet must, according to the conditions of the standard atmosphere, attain the magnitudes indicated in Table 19.

TABLE 19

Excess Pressure in G-Suit Airtight Helmet as a Function of Flight Altitude

1 Высота полета в км	12	15	18	21	25	30	50 и 2 выше
3 Избыточное давление в шлеме:							
4 в мм рт. ст.	0	54	88	109	125	136	144
5 в кг/см²	0	0,074	0,12	0,15	0,170	0,185	0,197

1) Flight altitude, in km; 2) 50 and higher; 3) excess pressure in helmet; 4) in mm Hg; 5) in kg/cm^2.

A good G suit must exhibit the following basic properties:

1) exert uniform counterpressure over the entire body surface, this counterpressure equal to the pressure of the gas in the lungs;

2) not restrict the movements of the pilot;

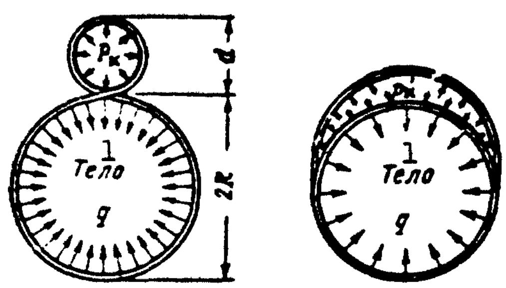
3) be air and vapor tight;

4) lend itself to being put on and taken off without outside help.

The operational principle behind a high-altitude G suit involves the fact that the surface of the body is subject to mechanical compression at a specific pressure equal to the pressure of the gas in the lungs. This is achieved by means of special tensioning devices which incorporate pneumatic chambers.

Figure 181 shows schematic diagrams of the operation of two types of tensioning devices.

The stress-bearing diagram of the device shown in Fig. 181a looks like a loop in the form of a figure eight in which the small circle houses the pneumatic chamber. As the chamber becomes filled with gas it straightens out, increases in diameter, and constricts the large circle, i.e., it reduces the perimeter of the suit.



a a)   b б)

Fig. 181. Schematic diagrams of two types of tensioning devices for the mechanical constriction of body surface (cross-sectional area). a) Diagram with circular pneumatic chambers, $q = P_k(d_k/2R)$; b) diagram with flat pneumatic chambers, $q \simeq P_k$. The solid line denotes the contour of the pneumatic chamber; the double thin lines denote the shell of the suit; P_k is the pressure inside the pneumatic chamber; q is the specific pressure of the suit against the body. 1) Body.

In the diagram shown in Fig. 181b, as excess pressure is developed in the chamber, the latter expands and concurrently presses one of its sides against the surface of the body while the other side draws in the shell of the suit. As a result pressure is exerted against the body surface over the entire perimeter.

The constriction devices of a G suit [VKK] are generally made in the form shown in Fig. 181a, since in this case the surface of the body is nowhere in contact with the rubber chamber, and as a result there is no impairment of the natural ventilation of the body. Devices made in accordance with the diagram shown in Fig. 181b are convenient and are

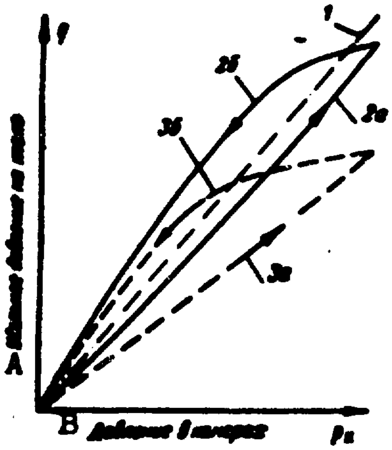


Fig. 182. Specific compression of body as function of pressure in chambers of constriction device. 1) Theoretical magnitude according to Formula (302); 2 and 3) specific compression of actual suit (2 – with proper prior testing; 3 – with improper prior testing of suit); a) forward stroke; b) reverse stroke of constriction device. A) Specific pressure against body; B) pressure in chambers.

used to exert pressure against the abdominal region, the hands, and the soles of the feet.

Let us determine the specific pressure against a body, produced by a suit made on the basis of the diagram shown in Fig. 181a. Without taking into consideration the frictional force, the tensioning T of the strap per unit length of generatrix will be

$$T = p_k(d_k/2) \text{ kg/cm}, \qquad (299)$$

where p_k and d_k are, respectively, the pressure in the chambers in kg/cm^2 and the diameter of the chamber in cm.

The tightening [tensioning] of the suit shell in turn is equal to

$$T = qR \text{ kg/cm}, \qquad (300)$$

where q is the specific compression of the body, in kg/cm^2; R is the curvature radius of the corresponding portion of the body, in cm.

Since the strap of the tightening device and the fabric of the suit shell combine to make up a series-connected stress-bearing system, the tension of the strap and of the suit shell are identical and, consequently,

$$p_k(d_k/2) = qR, \qquad (301)$$

from which we get the specific constriction of the body

$$q = p_k(d_k/2R) \text{ kg/cm}^2. \qquad (302)$$

The magnitude of the specific pressure q against the body must be equal to the excess pressure of the oxygen in the hermetically sealed helmet.

Figure 182 shows a qualitative distinction between the actual constriction of the body and the theoretical. The dashed straight line 1 corresponds to Formula (302). Because of the friction between the G suit [VKK] and the pilot's underwear, as well as because of the friction in the folds of the covering case of the tension chamber, the specific pressure exerted against the body is lower than the theoretical as the pressure in the chamber rises (curve 2a), while with a drop in pressure, conversely, the specific pressure is greater than the theoretical (curve 2b). Curves 3a and 3b in this same figure correspond to the case in which the movement of the straps of the tensioning system is smaller than the slack of the suit (for example, as a result of slightly loose fit). In this case, the compression of the body is inadequate (incomplete compensation). In order to reduce the danger of incomplete compensation, it is expedient to have as much play as possible in the tensioning system. This can be achieved by increasing the diameter of the tensioning chambers, or by increasing their number. In actual fact, if two or three series-connected tensioning devices of identical diameter are incorporated into the contour of the stress-bearing system, according to Formula (299) the constriction of the body will not change; however, there will be a significant increase in the total play of the tensioning elements. Therefore, in order not to increase the dimensions of the suit, as a rule two longitudinal tensioning chambers are incorporated along the frame of a VKK [G suit]. The sleeves and pant legs are restricted to a single chamber each. The position of the tensioning chambers can be seen from Fig. 183. Let us determine the pressure required in the chambers of the tensioning device. It follows from Formula (301) that

$$p_k = 2Rq/d_k \text{ kg/cm}^2. \qquad (303)$$

Expression (303) shows that the pressure in the tensioning chamber must be greater than the required counterpressure at the body by a factor which is equivalent to the extent to which the diameter of the corresponding portion of the body is greater than the chamber diameter.

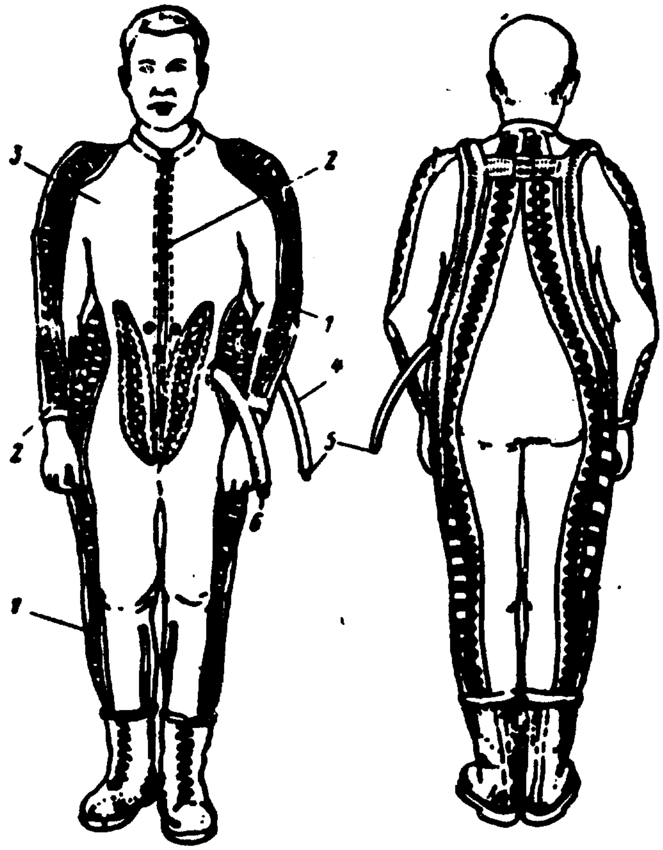


Fig. 183. Typical positioning of tension chambers on G suit (front and rear views of suit). 1) Pressure [tension] system; 2) zipper; 3) overalls; 4) rubber hose of pressure [tension] system; 5) connecting tube of pressure system; 6) connecting tube of G suit.

Let us assume that all the parts of a human body are circular in cross section and that the mean diameter of the chest cavity is equal to 32 cm, while the diameter of the chamber is equal to 6 cm. For the selected initial magnitudes, we obtain

$$p_k = \frac{32}{6} q;$$

i.e., the minimum required relationship of excess pressures between the airtight helmet and the pressure [tension] chambers amounts approximately to 1:5. Taking the frictional forces into consideration, we must raise the pressure in the chambers somewhat.

Since all of the tensioning chambers of a VKK [G suit] are most conveniently filled from a single automatic unit, it is obvious that the pressure in all of the chambers should be identical. Consequently, in order to ensure uniform specific pressure the stress-bearing covering cases of the tension chambers for the extremities must be made of slightly smaller diameter, in accordance with Formula (302). On the other hand, it should be borne in mind that VKK [a G suit] fails to provide for complete compensation over the entire surface of the body. Such areas as the armpits and shoulder blades, the groin, the elbows, and the knees are not subjected to adequate counterpressure and this may result in the concentration of blood at the extremities. In order to prevent this from happening, elevated constriction of the legs is employed. For the hands every effort is made not to introduce any significant increase in chamber diameter so as not to restrict movement or to increase dimensions. The final parameters of the tensioning devices are verified experimentally on test models.

The ratio between the pressure in the hermetically sealed helmet and the tensioning chambers in various types of VKK [G suits] produced by foreign firms is kept within limits of from 1:5 to 1:10.

The final selection of the relationship between the pressures in the airtight helmet and the chambers is a function of cabin, hatch, and seat dimensions.

Design of High-Altitude G Suit

A G suit consists of a pair of overalls with straps and pneumatic chambers. The overalls may be made of cotton, linen, capron, or nylon material. The material must be strong, light, permit the passage of air and vapor, and it must also exhibit a minimum coefficient of friction.

The suit is tailored so that the material is stretched as little as possible in the direction in which tension is exerted. The front of the overalls are open, but can be closed by means of a zipper. To facilitate the putting on and taking off of a fitted suit (i.e., a suit adjusted for the pilot's figure), the sleeves and pant legs are provided with zippered slits.

The tensioning device consists of a pneumatic chamber and straps which are wrapped around the entire length of the chamber, each turn separated by a width equal to the width of the straps. Figure 181a shows a schematic diagram of the tensioning system; an element of the tensioning system is shown in Fig. 184. The pneumatic chamber is made of rubberized material, or it comes in the form of a rubber chamber housed in a capron or nylon covering case. With the supply of oxygen

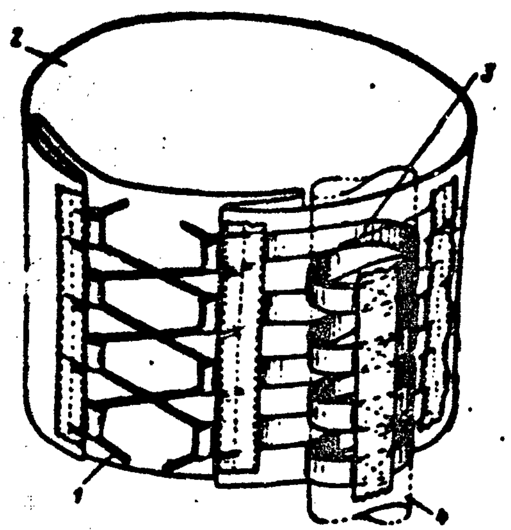


Fig. 184. Element of tensioning system used in VKK [high-altitude G suit]. 1) Lacing; 2) suit shell; 3) straps; 4) pneumatic chamber.

the chamber straightens out and tightens the overall material through the straps. A single chamber is installed in the suit along each sleeve and each pant leg, and there are two chambers on the torso. For greater mobility in the aircraft, the chambers are shaped so as to conform to the seated position of a pilot. When straight chambers are used at the knee and elbow joints, the chamber is fastened by means of a strip so that at this particular cross section the diameter is reduced by a factor of 3-4 (but a passage for the oxygen remains open).

Flat chambers are used in order to exert pressure against the abdominal cavity. High-altitude G suits [VKK] abroad are produced in 12 sizes. The suits weigh from 2.8 to 3.4 kg each. Lacing is employed to achieve individual fit of the suit in the diameter, and the lacing is found around the torso, the arms, and legs. After fitting, the slack in the suit should be slightly less than the play of the tensioning system.

Fitting and Using VKK

When a pilot receives a new suit he must, in cooperation with a suit technician, first fit and check the suit on his own body. The fitting of a suit is generally carried out in the following sequence:

1. The suit is put on, the zippers are closed, and an excess pressure of the order of 0.3-0.4 kg/cm^2 is generated in the tensioning chambers.

2. In seated position all laces are tightened (with the exception of those on the sleeves) so that the straps of the tensioning system remain with a play of 2-3 cm.

3. Gradually the pressure in the tensioning chambers is raised to the operating pressure. In this case, the margin of strap tension should not be determined before the pressure in the chambers reaches 90% of the maximum operating pressure.

4. The laces on the sleeves are tightened when the pressure reaches 70-80% of the operating pressure, so that the sleeves fit tightly about the arms.

5. When the pressure in the chamber reaches 90-100% of the operating pressure, a check is carried out to determine whether the suit is exerting pressure against the body uniformly, whether the pressure is causing local pain, and to make certain that no intolerable impairment of movement results.

A properly selected (with respect to size) and fitted suit is evaluated subjectively by determining whether or not a pilot has complete freedom of movement when there is no pressure in the tensioning chambers, and if pressure is developed in these chambers whether he senses uniform compression against all surfaces of the body, with insignificant restriction of movement.

Improper (somewhat too loose) fitting of the suit may produce sudden loss of consciousness.

Jersey undergarments (positively without buttons and straps) are worn beneath the G suit, and these produce minimum friction against the material of the suit.

Depending on the time of the year and the theater of operations, conventional flight clothing is worn over the G suit. It is important for the jacket to have a zippered opening in the center to permit passage of the straps for the regulator of helmet tension.

G suits may also be used in combination with waterproof survival suits.

Design of Airtight Helmets*

For flights higher than 15-17 km, the G suit is used together with an airtight helmet [known in Russian abbreviation as a "germoshlem" – GSh]. The airtight helmet completely protects the pilot's head against the outside atmosphere. The sealing off of the helmet is achieved about the neck by means of a multisectioned rubber valve. As has already been pointed out, the airtight helmet serves all functions of the oxygen mask. Moreover, it provides ideal pressure compensation about the surface of the head. The airtight helmet also protects the face and head of a human being against the effects of ram pressure on ejection, as well as against the accidental striking of the head against objects.

The magnitude of the required excess oxygen pressure in an airtight helmet [GSh] was given in Table 19.

Unlike an oxygen mask, the following additional requirements are imposed on an airtight helmet:

1. The open space of an airtight helmet [GSh] should not be overly large, to provide for normal operation of the automatic lung and to ensure a low concentration of carbon dioxide in the inspired air (with an excessively large free space the expansion resulting from inspiration may be inadequate to set the automatic lung into operation).

2. The helmet must satisfy hygienic requirements with respect to ventilation and protection against radiative heat.

3. The helmet should not restrict visibility, fog over, or impair head movement.

4. The helmet must be of minimum weight (this is particularly important at the instant of acceleration on seat ejection when the pilot finds his head forced forward; a heavy helmet may damage the neck vertebrae).

5. The helmet must have a movable light filter for use when flying into the sun.

6. The visor of the helmet must exhibit good optical properties and produce no distortions (the angular shift with normal ray incidence should be no more than 5').

7. It should be possible to put on and remove the helmet visor with one hand.

Figure 185 shows one of the most popular types of airtight helmets. This hermetically sealed helmet consists of three basic units: a face frame 1 with a helmet liner; a helmet 2; and a transparent visor 3. A thin rubber helmet liner 4 is hermetically sealed to the face frame, and this liner is fitted out with a valve to ensure the airtightness of the helmet about the neck. The rubber liner is covered with a stress-bearing material liner 5 which is attached to the same

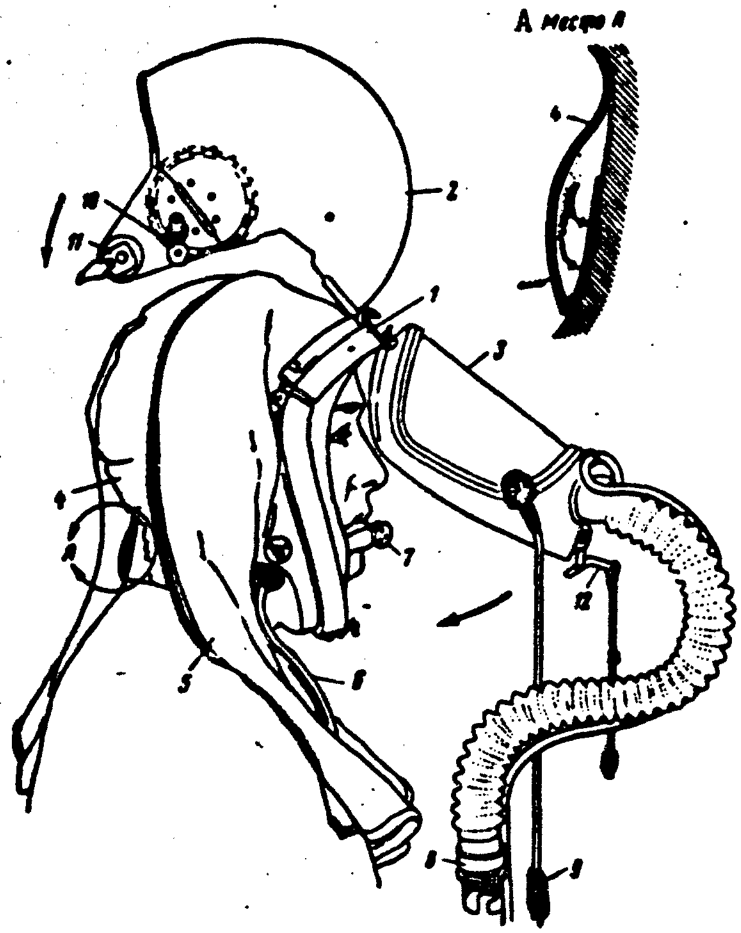


Fig. 185. Design of contemporary airtight helmets, employed as part of regular Air Force equipment in many foreign countries. 1) Face frame with soft helmet liner; 2) helmet; 3) transparent visor; 4) airtight rubber helmet liner; 5) strong helmet liner of material; 6) bundle of communications leads; 7) microphone; 8) oxygen hose; 9) window-heat leads; 10) helmet tensioning roller; 11) helmet release; 12) visor release. A) Position A.

face frame. The material liner is provided with laces for purposes of regulation and a zipper to permit rapid donning. At the bottom the liner terminates in a neckpiece which is worn beneath the G suit to prevent its creeping out as excess pressure is generated in the helmet. The rigid helmet is fastened to the face frame at three points, i.e., on top at the center, and at the sides. The helmet contains an adjustable soft section designed to permit change in helmet depth as it is fitted on the person. The transparent visor is fastened to the face frame at 2 points, i.e., suspended from a hook at the top, and tightened at the bottom by means of a catch.

The airtight sealing of the visor is achieved either on the basis of the "knife against rubber" principle, or by pressing an inside valve to the surface of the visor. The transparent visor [face plate] is made of plexiglas, two pieces bonded together, with heating elements consisting of wires 0.03 mm in diameter between the plates. The spacing between the wires is about 0.25 mm. This electrical heating provides a temperature of 30-37°C on the inside surface of the glass and completely protects the glass against fogging over and icing. The specific power of the electrical heating for various types of helmets ranges between 0.08 and 0.15 w/cm². Figure 186a shows the required specific pow as a function of the temperature difference between the inside surface of the helmet glass and the outside air, the latter calculated on the basis of the conventional heat-transfer formulas in which convection and radiation have been taken into consideration on the basis of a heat-transfer coefficient $\alpha = 6$ kcal/m²·hr°C.

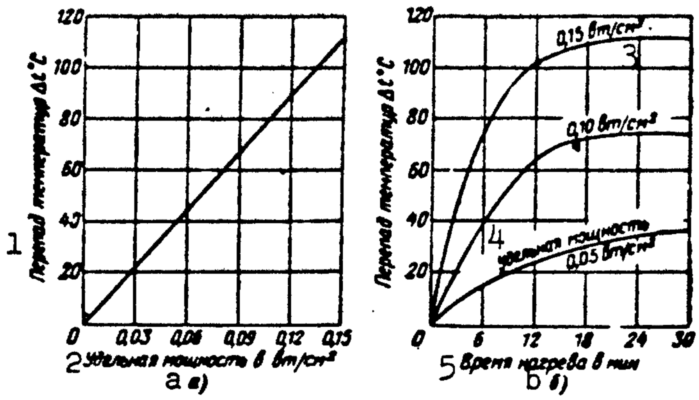


Fig. 186. Characteristics of electrically heated visor plates of hermetically sealed helmets (in quiescent air). a) Temperature difference between inside surface of plate and the outside air as a function of the specific heating power; b) heating time for plate with various specific powers. 1) Temperature difference Δt °C; 2) specific power in w/cm²; 3) 0.15 w/cm²; 4) specific power; 5) heating time, in minutes.

The time required for the heating of the plexiglas plate as a function of the specific power is shown in Fig. 186b. The plate temperature is controlled manually by means of a rheostat or automatically. The sensing element of the automatic temperature regulator is a miniature thermistor glued into the plate.

A balanced outlet [expiration] valve is mounted in the lower portion of the visor plate (the same as shown in Fig. 174) and an inspiration valve is also attached here, with the corrugated hose that connects to the on-board oxygen supply connected to the frame of this latter valve.

As excess pressure is developed a rather great force directed upward is exerted on the helmet, this force being equal to the product of the excess pressure and the area difference between the cross section of the helmet (at its greatest points) and the neck. With an excess pressure of 0.2 kg/cm^2 (corresponding to a flight at an altitude of 36 km and higher) this force is, on the average, equal to 70 kg. To keep the helmet on the head and to prevent its shifting upward, there is a tensioning device provided for the helmet (see Fig. 170a). There is a single roller on each side of the helmet, and these are suspended from free-swinging hinges. A thin cable is passed through each of the rollers and this cable is fastened by means of snap hooks to rings that have been sewn, for this purpose, into the G suit. The tensioning system of the helmet is provided with a length control that is operated at will by the pilot by tugging at the strap passed through self-gripping buckle. Partial automation of cable tightening can be achieved by taking advantage of the pressure in the chambers of the suit.

When the helmet is on communications are effected by means of telephones or a microphone mounted generally on a headset worn directly on the head. The quality of communications depends in great measure on the distance between the microphone and the lips. If the microphone is mounted on a special bracket as part of the headset, the position of the microphone is virtually independent of the position of the GSh [airtight helmet] which may nevertheless shift upward under the action of the excess pressure.

Other types and designs of hermetically sealed helmets are presented in Fig. 187.

The airtight helmet shown in Fig. 187d has a rigid plastic helmet (for example, made of fiberglas or glass textolite) which covers the entire head, and a visor which can move radially upward and can be fixed in this position. The light filter is mounted inside the helmet. This procedure makes it possible to automate the closing of the visor.

The semirigid airtight helmet shown in Fig. 187b is equipped with a permanently closed viewing visor. To prevent fogging of the plastic plate, the latter is designed of two panels which a clearance (there is no information as to whether or not a vacuum exists in this clearance).

There is an opening with a cover in the lower portion of the face frame of the helmet, this orifice intended for breathing on the ground and for the intake of food.

The airtight helmet shown in Fig. 187e is of interest because the sealing valve is positioned between the neck and a ring on which the helmet turns. This makes it possible to remove the helmet and put it on again easily, thus providing great operational convenience, since it enables the pilot during the hot season to prepare for takeoff without having to remain enclosed within the helmet.

Some of the airtight helmets from among those shown in Fig. 187b, c, and d have the mask incorporated as part of the design (these types of helmets are common in Great Britain). The significance and purpose of the mask is to reduce the volume of dangerous space and thus to reduce the carbon-dioxide content in the inspired air, as well as to reduce the humidity of the air in the vicinity of the visor plate. Such a mask, fastened not to the face but to the forward portion of the helmet is not completely airtight; however, this is safe since the entire helmet is filled with oxygen.

The Oxygen System of a High-Altitude G Suit

In the event of cabin depressurization at altitudes in excess of 12,000 m, the excess pressure in the lungs and the balancing counterpressure of the G suit against the body must be generated automatically and without delay, within a period of time not to exceed 3.5 seconds. In this case, so as not to damage the lungs, the rise in pressure in the suit chambers must precede the appearance of excess pressure in the lungs by 0.5-1.5 seconds. This represents the main feature of the oxygen system employed in a high-altitude G suit.

Figure 188 shows one of the possible block diagrams of a VKK [G suit] oxygen system. In addition to the oxygen sources for the suit and airtight helmet, the system includes an on-board oxygen unit with an acceleration-blocking mechanism 8, a consolidated release 12, a parachute oxygen unit 11, a pressure-ratio regulator 9, and the corresponding plumbing (hoses). The connection tubes located along the line A-A are used to connect the airtight helmet and the suit once the pilot is seated in the cabin. The separation of the hoses connected to the common release 12 in the event of ejection takes place along the line B-B [Б-Б].

Below an altitude of 12 thousand meters the pilot's supply of oxygen is provided by the on-board oxygen equipment whose operational principle is analogous to that of the excess-pressure equipment (see Fig. 176). Above 12 km diaphragm valves installed in the blocking mechanism provide for the rapid filling of the suit chambers with oxy-

Fig. 187. Various types of foreign airtight helmets used in conjunction with G suits. a) Mass-produced USAF helmet; b) helmet with sewn-in double visor plates and mouth hatch; c and d) helmets with movable plates and hatches for food intake (these helmets are used by English test pilots); e) helmet on rotating bearing (experimental helmet, USA).

gen (within 2-3 seconds), with subsequent automatic switching to continuous feed at a rate of 15-20 standard liters per minute, this being required to compensate for losses and to develop the excess pressure.

The pressure-ratio regulator 9 apparently consists of two regulators connected within a single frame, i.e., the pressure regulator in the helmet and the pressure regulator in the tension chambers of the suit. This regulator prevents the untimely rise in mass or helmet

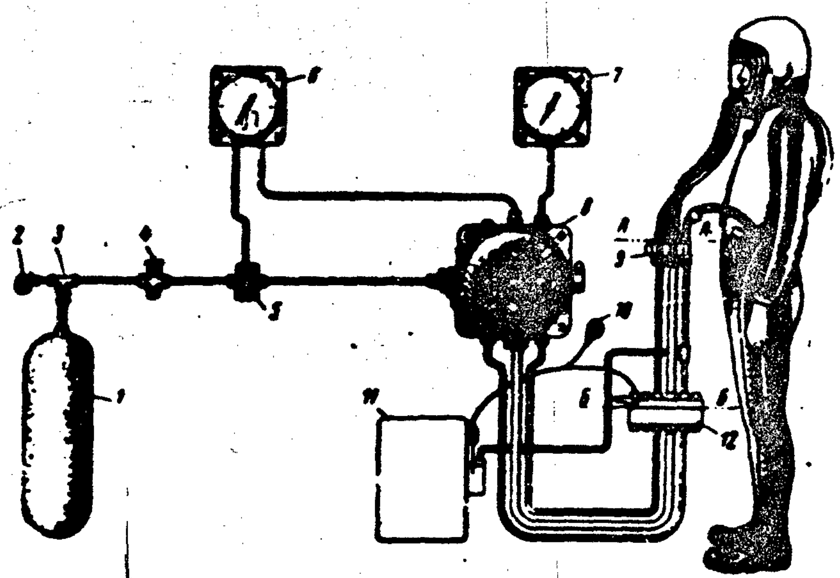


Fig. 188. Typical block diagram of oxygen system for high-altitude G suit. 1) Oxygen bottle; 2) on-board charging connection tube; 3) T-joint with return-flow valve; 4) stopcock; 5) pressure-reduction unit; 6) oxygen flow-rate indicator with manometer; 7) pressure manometer in breathing system; 8) on-board oxygen unit with blocking mechanism; 9) pressure-ratio regulator; 10) manual actuation of parachute unit; 11) parachute oxygen unit; 12) consolidated release.

excess pressure during the initial period in which the chambers are filled up, and then it maintains the given pressure ratio between the helmet and the chambers. On ejection and transition to the oxygen supply from the parachute equipment this regulator maintains the given pressure regime in the helmet and the suit. The pressure-ratio regulator is generally positioned on the hoses between the parachute unit and the suit.

Figure 189 shows another possible version of an oxygen system for a high-altitude G suit, as produced by the French company Intertechnique Boulogne-Billancourt.* In this system the parachute oxygen equipment is fitted out with an automatic lung 8 and a pressure regulator 9 which automatically connects the supply of pure oxygen from the emergency bottle 7 if the cabin altitude exceeds 12,200 m. On seat ejection, for purposes of separating from the on-board system, provision has been made for releases 5 and 6, fitted out with stop (return-flow)

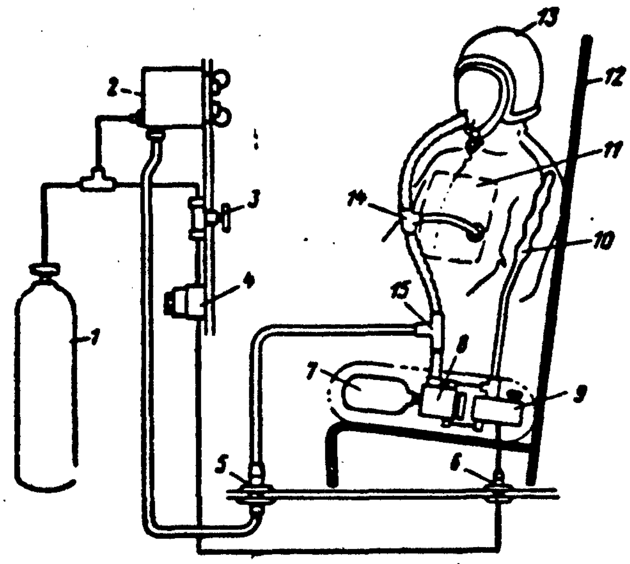


Fig. 189. Block diagram of the oxygen system used in the high-altitude G suit produced by the Intertechnique Boulogne-Billancourt Company. 1) On-board oxygen bottle; 2) on-board oxygen equipment (automatic lung); 3) valve; 4) pressure-reduction mechanism; 5 and 6) disconnect sleeves with return-flow valves; 7) bottle with emergency oxygen reserve; 8) automatic lung; 9) pressure regulator of emergency oxygen system; 10) suit tension chambers; 11) breathing chamber; 12) seat; 13) airtight helmet; 14) pressure regulator of breathing system; 15) distributor valve.

valves.

One of the shortcomings of a conventional G suit in breathing at high altitudes under excess pressure is the fact that additional muscular exertion is required on inspiration and the chest cavity experiences no compensating counterpressure on expiration. These factors lead to rapid pilot fatigue and may disrupt the circulatory system and the supply of oxygen to the organism. To ease breathing under excess pressure, a pneumatic chamber 11 is placed beneath the suit shell in the chest area (Fig. 189), this chamber connected to the inspiration line of the oxygen equipment. With such a breathing chamber the pilot during inspiration draws in oxygen from the chamber and the counterpressure against the chest cavity is reduced, whereas during expiration the chamber, conversely, fills with oxygen as a result of the continuous feed from the equipment and the pressure in the chamber rises, thus easing expiration. With a G suit equipped with this auxiliary breathing chamber the time during which it is possible to remain at higher altitudes increases severalfold in comparison to operations with a suit not equipped with such a chamber. A drawback of the chamber is the slight impairment of hygienic conditions, i.e., the ventilation of the body in the chest area is curtailed. The tension chambers of the pressurized gloves are connected to the breathing chamber by means of thin tubes situated along the sleeves.

Since during the course of a flight an emergency develops suddenly, the flight crew must be trained in advance and become familiar with the handling of the VKK [G suit] equipment and the oxygen apparatus on the ground and in a pressure chamber.

Special training oxygen equipment is used for purposes of learning to breathe at elevated pressures under ground conditions, and this equipment makes it possible exactly to regulate the excess pressure in the breathing system (the same equipment determines the magnitude of leakage from the oxygen masks). An advantage of the KP-T is the fact that it provides for small fluctuations in excess pressure in the helmet (or mask) during inspiration and expiration, which cannot be achieved under ground conditions when using the manual elevated-pressure regulator of the on-board oxygen equipment.

Prior to each takeoff, after assuming his position in the aircraft, the pilot must generate the operating excess pressure in the breathing system and in the suit for a period of 1-2 minutes, personally verifying the proper functioning of the entire equipment complex.

§6. HIGH-ALTITUDE SPACE PRESSURE SUITS

General Data and Classification

In the event of aircraft cabin depressurization at high altitudes (in excess of 12,000 m) prolonged continuation of flight without reducing altitude and completion of the mission can be achieved only by means of a high-altitude space pressure suit. Moreover, the space pressure suit serves for purposes of pilot survival on ejection from the aircraft at great speeds and altitudes. The space pressure suit is also used to deal with problems of protecting man against the effects of low and high temperatures and for water survival.

According to foreign literature, the high-altitude space pressure suit is an airtight pair of overalls connected to a helmet.* In terms of operational principle, the space pressure suit is analogous to a pressurized cabin, i.e., it is a very light, elastic, gastight "cabin," described about the body and equipped with hinges at the points of the major joints.

On depressurization of the aircraft cabin, the absolute air pressure in the space pressure suit is generally kept equal to the pressure of an altitude of 10,700-11,500 m. Under conditions of a complete vacuum this corresponds to an excess pressure of 0.24-0.21 kg/cm^2, which is completely adequate when breathing pure oxygen. Setting the "altitude" in the space pressure suit within limits of 10,700-11,500 m can be explained by the effort to draw the greatest possible advantage from a compromise between inadequate mobility of the shell under considerable excess pressure and the conditions under which high-altitude sickness sets in.**

However, when a man experiences high-altitude pains in the joints, it is desirable to descend to an altitude of 8000 m which is equivalent to the generation of an excess pressure of 0.35 kg/cm^2 in the space pressure suit. In a pressurized cabin the excess pressure in the space pressure suit does not exceed 0.02 kg/cm^2 (200 mm water column).

In addition to satisfying the above-indicated requirements with respect to the magnitude of the absolute and excess pressures, in the opinion of foreign scientists a space pressure suit must exhibit the following properties:

1) it must have good mobility, enabling the pilot to execute all necessary movement;

2) it must provide adequate visual freedom;

3) it must be strong (a static strength margin of about 3), light in weight, gastight, and ozone resistant;

4) it must ensure hygienic conditions with respect to ventilation, moisture and carbon-dioxide removal, and temperature control;

5) it must be easy to put on and fit with respect to height, exerting no painful pressure against the body;

6) it must be capable of floating and be water repellant, and it should also provide protection for the pilot in cold water.

Depending on the ventilation method and oxygen supply high-altitude space pressure suits are subdivided into ventilation and regeneration units. Each of these two types of space pressure suits can be produced with or without a mask, i.e., with an oxygen mask on the face (inside the airtight helmet) or without a mask.

Basic Space Pressure Suit Design*

A typical diagram of a ventilation space pressure suit with a mask is shown in Fig. 190a. The ventilation air for the space pressure suit is taken from the compressor of the turbojet engine, it passes through the flow-rate and temperature regulation assemblies and enters the shell of the suit, in which special tubes and panels propagate the air throughout the entire inner space of the suit. Thus water vapors and carbon dioxide liberated from the body are removed.

The pilot receives his oxygen through a mask from on-board oxygen equipment of the automatic-lung type, similar to the way shown in Fig. 175. The only difference between the automatic lung intended for operation in conjunction with a space pressure suit and conventional equipment is the fact that the outside cavity of the membrane is hermetically sealed and connected by means of a tube to the shell of the space pressure suit. If this is not done, as excess pressure is built up in the space pressure suit the membranes will not shift as a result of the rarefaction generated by inspiration, the inlet valve of the automatic lung will not open up, and no oxygen will enter the mask.

During a parachute descent the oxygen supply is received from the parachute equipment which is actuated automatically at the instant of ejection. In the case of engine failure the emergency pressurization of the space suit is carried out automatically with the aid of a special on-board tank. The sensing element in this case is the diaphragm box fitted with contacts that actuate a solenoid valve. The air which ventilates the shell and helmet of the space pressure suit, as well as the oxygen, are passed into the atmosphere through the pressure regulator in the shell of the suit. This regulator freely releases all of the gas below altitudes of 8-11.5 km, while at higher altitudes it maintains a constant absolute pressure in the space pressure suit. Moreover, the space pressure suit is equipped with a safety valve which is set for the maximum excess pressure which the strength of the given shell can withstand. To prevent the fogging of the visor plates, the expired air is removed through the expiration hose which is found between the soft material curtain separating the helmet and the frame.

The ventilation-type space pressure suit without a mask (Fig. 190b) differs from the equipment just described in that at high altitudes pure oxygen is fed into the helmet and only the extremities and torso are ventilated with air.* The helmet is separated from the frame by means of an airtight curtain made of thin rubber.

If a large-volume helmet is used with a space pressure suit of

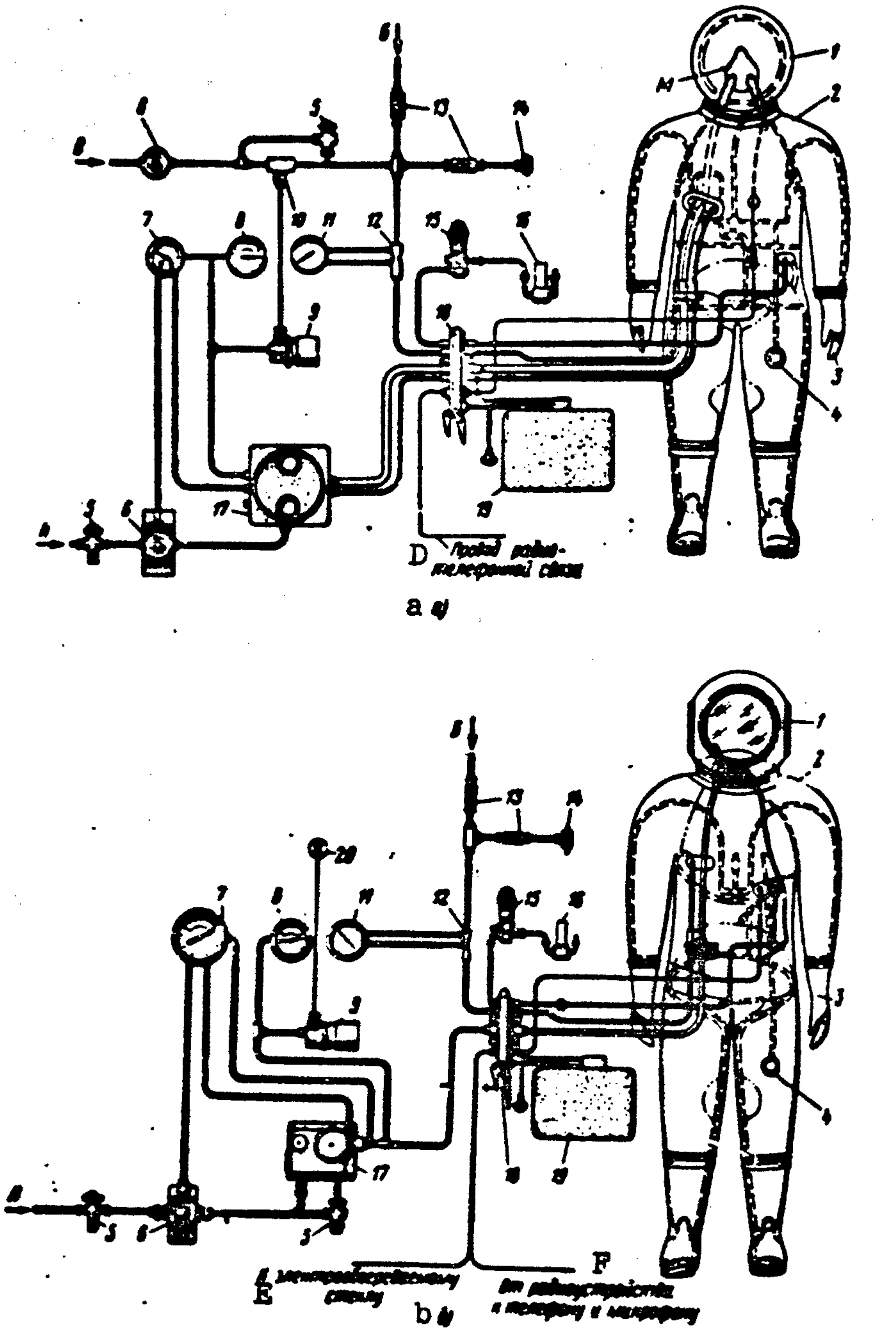


Fig. 190. Schematic diagram of ventilation-type space pressure suit (a – with mask; b – without mask). A) Oxygen from on-board bottles at pressure up to 150 atm; B) air supply from on-board climatization system; C) air from on-board emergency bottles; M) oxygen mask. 1) Helmet; 2) shell; 3) airtight gloves; 4) space pressure suit pressure regulator; 5) stopcock; 6) pressure-reduction mechanism; 7) flow indicator with manometer; 8) altitude indicator and pressure-difference indicator; 9) altitude danger signal; 10) solenoid valve; 11) air flow-rate indicator; 12) metering tube; 13) return-flow valve; 14) ground ventilation connection tube; 15) automatic pressure mechanism of antigravity unit; 16) air filter; 17) on-board oxygen equipment; 18) consolidated release; 19) parachute oxygen equipment; 20) warning light. D) Radiotelephone communications lead; E) to electrically heated plates; F) from radio unit to telephone and microphone. A = A; = B; B = C.

this type, continuous helmet ventilation by means of an oxygen-air mixture or pure oxygen in quantities of about 40 liters per minute are required for purposes of removing the carbon dioxide. The ventilation of the helmet is achieved by means of a continuous-feed oxygen unit, and it is enough to pass a rather thin hose from this unit to the helmet of the space pressure suit.

In the case of a small-volume helmet (for example, the rotating helmet shown in Fig. 170b), it is possible to use the automatic lung, or a combined piece of equipment in which the automatic lung is operated in conjunction with a continuous-feed mechanism.

The relative humidity of the air in the helmet of a space pressure suit without a mask is higher than in the case of a suit with a mask, since the air is expired into the helmet. Therefore, in order to guard against the fogging of the visor plates the helmet of a space pressure suit without a mask is made of two plates with an air clearance or with electrical heating. In all other respects, the two ventilation space pressure suits are identical.

It should be pointed out that the hygienic conditions for the human head with respect to ventilation and the temperature regime in the case of a space pressure suit without a mask are somewhat inferior to the mask version. Damage to a helmet without a mask and the disruption of its airtightness leads to the danger of oxygen starvation, but at the same time the helmet exhibits the following advantages:

1) there is no mask which can press against the face and irritate the skin;

2) vomit represents no danger (with a mask the vomit could clog the valves).

In order to complete the comparison of the mask and maskless space pressure-suit ventilation-type versions, let us calculate the oxygen flow rate for the space pressure suit without a mask, proceeding from the following two conditions:

1) the total supply of oxygen and air through the helmet is equal to 40 liters per minute:

$$G_{O_2}\frac{p_0}{p_H}+V_a=40 \text{ l/min;} \qquad (304)$$

2) the oxygen content in the gas mixture corresponds to the given O_2 percentage:

$$t_{O_2}=\frac{\left(0.21V_a+G_{O_2}\frac{p_0}{p_H}\right)\cdot 100}{40}\ \%. \qquad (305)$$

Solving Eqs. (304) and (305) simultaneously, we will obtain

$$G_{O_2}=\frac{40(t_{O_2}-21)p_H}{79p_0} \text{ stand. l/min.} \qquad (306)$$

The results of the calculation performed in accordance with Formula (306) are shown in Fig. 191. The required oxygen flow rate is calculated for two values of oxygen concentration, i.e., the required minimum (according to Table 16) and the flow rate corresponding to actual equipment (see Fig. 172, the curve for v_1 = 15 liters per minute). This same graph also shows the oxygen flow rates in the case of equipment with periodic feed, operating in conjunction with the space pressure suit. In the latter case the volumetric oxygen flow rate is equal to the lung ventilation, since if even only slight excess pressure is present in the space pressure suit the return-flow valve in the automatic air intake closes and the drawing of air from the atmosphere (from the cabin) ceases.

From these graphs we can see that at an altitude of 7-8 km, given lung ventilation of 15 liters per minute, the oxygen flow rate in the case of the space pressure suit without a mask is higher than in the case of a space pressure suit using a mask, and this by a factor of almost 2.

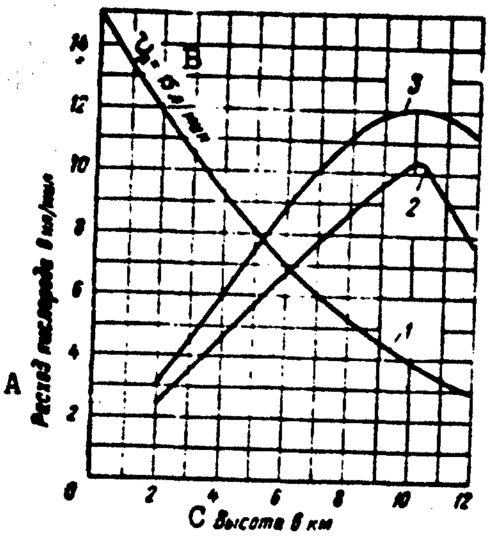


Fig. 191. Mean oxygen flow rate for ventilation-type space pressure suit with and without masks. 1) O_2 flow rate for space pressure suit with mask, in the case of lung ventilation of 15 liters per minute (with air intake shut off); 2) minimum required O_2 flow rate for space pressure suit without mask; 3) probable O_2 flow rate with actual equipment for space pressure suit without mask. A) Oxygen flow rate, in standard liters per minute; B) $v_1 = 15$ liters per minute; C) altitude, in km.

Regeneration-type space pressure suits are generally used without oxygen masks. The removal of carbon dioxide and water vapors from the expired air is carried out in absorption cartridges through which the gas flows in a continuous stream to fill the free space of the space pressure suit. The energy source for the circulation is provided by an injector which takes advantage of the compressed oxygen in the bottle, or a ventilator with electric drive is provided.

A schematic diagram of a regeneration system for space pressure-suit supply is shown in Fig. 192. The gas is drawn out of the space pressure suit by means of injector 2, it passes through the carbon-dioxide absorption cartridge 9, then through the moisture-absorption cartridge, from which it is returned to the helmet and the space pressure-suit shell. A specially prepared hydrate of calcium oxide may be used as the absorption agent for the carbon dioxide, and silica gel is used to absorb the water vapors. The maximum absorptive capacity of 1 kg of these materials is, respectively, 120-150 liters of carbon dioxide and 350-400 g of water vapors.

There are chemical substances which can liberate oxygen while simultaneously absorbing carbon dioxide (CO_2) and moisture. It should be stressed that the substances known to be capable of absorbing CO_2

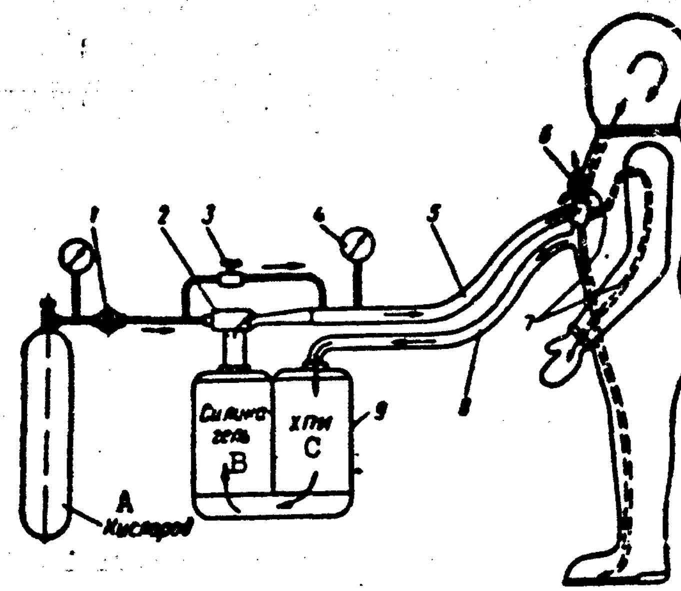


Fig. 192. Schematic diagram of regeneration-type space pressure suit. 1) Pressure reducing mechanism; 2) injector; 3) cock; 4) manometer; 5) oxygen supply hose; 6) pressure-difference regulator; 7) distributor tubes; 8) hose for removal of waste oxygen; 9) absorption cartridges. A) Oxygen; B) silica gel; C) KhPI [not specifically identified in text; probably refers to chemical absorbent of carbon dioxide].

can be employed only at positive temperatures and if water vapors are present in the gaseous mixture.

If it becomes necessary to regulate temperature along the circulatory path of a closed gas circuit; heat exchangers for purposes of heating or cooling may be set up.

In order to develop pressure in a regeneration-type space pressure suit and to balance the losses through the shell, oxygen from a bottle is fed continuously through a pressure-reducing mechanism and a calibrated orifice. The nozzle of the injector could be employed as this orifice.

The magnitude of the oxygen supply must exceed the magnitude of the leakage losses and in the case of a regeneration space pressure suit generally amounts to 3-5 standard liters per minute. For ventilation-type space pressure suits a somewhat higher rate of leakage loss can be tolerated, the maximum of this loss being limited by the average magnitude of the oxygen supply available from the parachute oxygen equipment.

Future space pressure suits will apparently be of the regeneration type.* These pressure suits must exhibit the highest order of airtight closure. They will be confronted with the problem of removing carbon dioxide and generating oxygen by completely new methods. The successful solution of this problem is possible if it becomes possible to apply photochemical processes for this purpose, using direct or converted solar energy.

Space Pressure-Suit Design**

Basically, a space pressure suit consists of two fundamental parts, i.e., an airtight shell and a helmet (Fig. 193). The shell is provided with removable airtight boots and gloves.

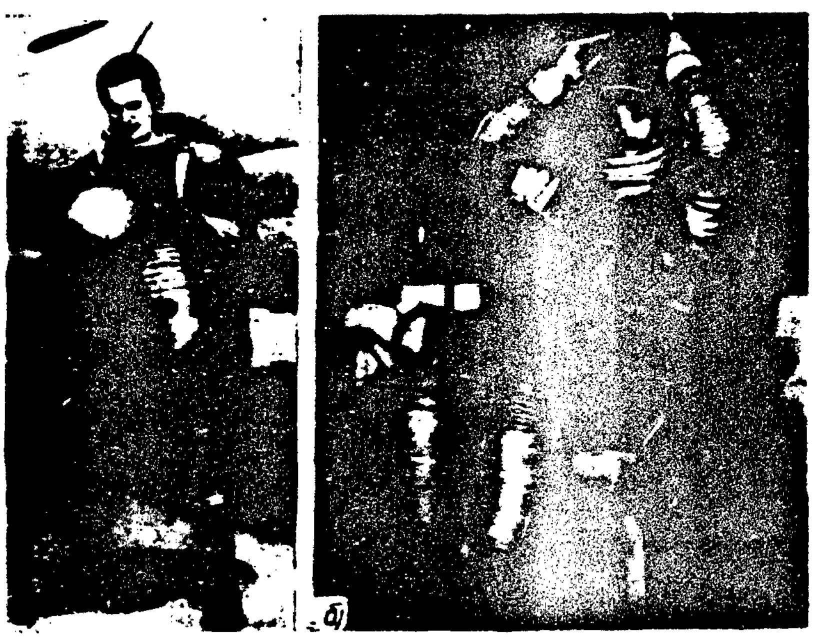


Fig. 193. General view of Goodrich space pressure suits made of rubberized fabric with corrugated articulation. The helmet turns on an airtight bearing. a) A 1956 space pressure-suit model; b) a 1958 space pressure-suit model.

The problem of developing a flexible, strong, airtight, convenient, and light shell has not been completely resolved to the present time.

The principle of constructing a soft space pressure-suit shell is based on the fact that any soft shell under the action of internal excess pressure tends to assume the shape of a body of revolution. It is therefore expedient to represent the human body as consisting of intersecting bodies of revolution: the torso, represented as a cylinder; the pelvis and the buttocks as hemispheres; the hips, shins, and forearms as truncated cones, etc. Proceeding from specific perimeters of parts of the human body, taking into consideration the thickness of the inside clothing and the slight clearances for air, the designers construct a shell about such an idealized shape and evolve all elements of the shell with precision, regarding the shell as a solid body. Rejection of this principle leads to the appearance of elevated local stresses at the points at which the individual parts of the shell are connected, it leads to a reduction in the strength safety margin, and freakish deviations from the anticipated shape.

At the points corresponding to the position of the joints on a human body, hinges are installed in the shell (see Figs. 170b and 193). As a result, it is possible to achieve satisfactory mobility both without excess pressure and with an operating pressure difference between the shell and the atmosphere.

One of the significant features of a material shell (unlike metals) is its significant elongation under the action of internal pressure. If this elongation is not restricted, the helmet of the space pressure suit rises considerably above the head of the man, and the armholes of the sleeves will cut in beneath the arms. Therefore, each shell is provided with a stress-bearing system consisting of thin laces which can be employed to regulate length and which blocks the "growing" of the space pressure suit and serves for the individual fitting of the shell with respect to height and length of extremities.

There are two basic types of soft space pressure-suit shell constructions:

1) a single shell of airtight (generally rubberized) two- or three-ply material over which a stress-bearing system is imposed and

2) a space pressure suit with individual shells, the inside rubber shell ensuring the airtightness, the outer shell serving as the stress-bearing system and offering protection against accidental mechanical damage. This outer shell may be connected to the suspension system of the parachute, and if it is fabricated of flameproof aluminized fabric it offers additional protection for man against radiative heat in supersonic flight and against fire.

In the fabrication of the first type of shell – made of rubberized fabric – it is in all cases expedient to put on light clothing above the space pressure suit in order to protect the latter against chance scratches and tears.

There are many structural solutions and methods of donning a space pressure suit. The most popular is the open front, as in the case of overalls, making it possible for the pilot to put on and remove the space pressure suit by himself. The hermetic sealing of the open front is generally achieved by means of a wide cylindrical throat-like constriction made of thin gasproof fabric sewn into the suit (the so-called appendix) which is screwed in and tied shut after the shell has been put on. These open fronts are also used to ensure the airtightness of water survival suits.

There are airtight and stress-bearing zipper designs, but from the operational standpoint they are less reliable than the appendix. Occasionally the pressure suit is put on through a rigid joint separating the shell into two parts, i.e., in the form of a belt, a "false front" as in the case of diving suits, or a chest connection (along the diagonal from shoulder to belt). All of these solutions lead to more cumbersome and heavier designs than the open-front type appendix or the airtight zipper. Rigid elements placed on the chest can be justified only from the standpoint of offering additional protection for the human being against extremely great ram pressure in the event of ejection.

The hinged joints of space pressure suits represent the most difficult elements of the design. The simplest solution is given by elbow and knee joints bending in a single plane at an angle not in excess of 160°. This is achieved by means of additional slack – "orange peels," as shown in the diagram in Fig. 194. The longitudinal tensioning laces are positioned along neutral generatrices whose length does not change when bent.

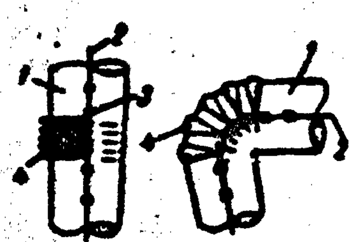


Fig. 194. Diagram of "orange peel" type of hinge. a) Straightened position; b) bent position. 1) Shell; 2) longitudinal stress-bearing lace; 3) guide laces fastened to the shell; 4) element of hinge shell in the form of a "orange peel."

Mobility for the shoulder and pelvis-hip joints which execute rotational and translational motion in all planes, is the most complex of the problems to resolve, since the center of these natural Guk [sic] joints lies inside the body. The hinged joints corresponding to these natural joints are for the most part made in the form of "accordion pleats" provided with additional braces which slide over rollers or along guide rails (see Fig. 193).

In order to achieve good mobility for the arms, the space pressure suits are also fitted out with airtight bearings at the shoulder and elbow (or wrist) joints (see Fig. 170b). The shoulder airtight bearing provides for the free movement of hands in the vertical plane. The bearing above and below the elbow or between the hand and the forearm makes it possible to turn the arm about its longitudinal axis, which is necessary to control the numerous assemblies, instruments, and switches of a contemporary aircraft.

The airtight bearing must simultaneously exhibit a high degree of airtightness and its moment of rotation must be small.

Ease in walking is achieved by using radial-support bearings, and airtightness is achieved by means of slide valves. The inside valve ensures the hermetic sealing of the gas while the outside valve prevents the entry of water into the shell.

The shoulder bearings provide good mobility for the hands when working in a space pressure suit with excess pressure; however, in the case of a prolonged flight local shoulder and chest-muscle pains may result, even if there is no pressure in the shell.

The designer, having satisfied the numerous requirements imposed on a space pressure suit, seeks first of all to provide the pilot with normal operating efficiency in a properly functioning pressurized cabin. Therefore, a tendency to use soft joint hinges wherever possible in order to have minimum shell weight and operational convenience in the basic operational regime, i.e., in the pressurized cabin, has been detected in space pressure-suit development.

For purposes of providing a better fit of the space pressure suit to the form of a seated man and to facilitate movement over the airfield, a zipper is incorporated into the stress-bearing shell across the abdomen (on bulwarks) (see Fig. 170b). This zipper is kept open when walking and is closed after the pilot has been seated.

In order to reduce the diameter of the sleeves and pant legs, these are sometimes fitted out with laces. Reducing the diameter leads to a reduction in the force required to bend the hinged joint, and the lacing facilitates the donning of the shell.

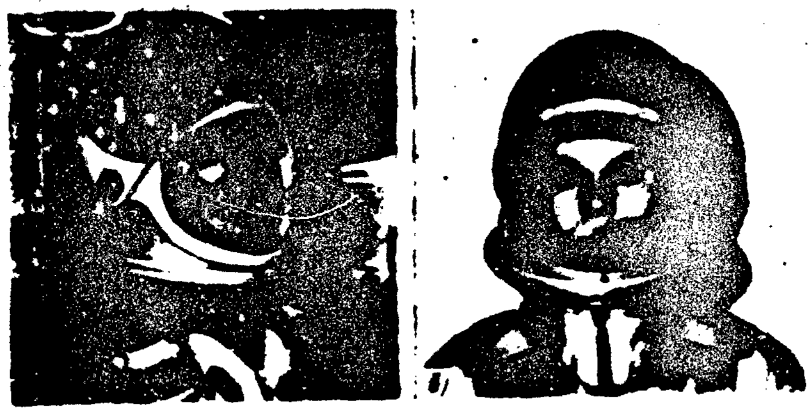


Fig. 195. Contemporary rotating helmets used in foreign space pressure suits. a) Helmet for a space pressure suit by the Arrowhead Rubber Co.; b) helmet for space pressure suit by the Goodrich Company.

The most "unpleasant" dimension of the space pressure suit from the standpoint of an aircraft-cabin and ejection-seat designer is the width across the shoulders. For a space pressure suit with soft shoulder hinged joints, corresponding to a commercial suit size of 52-54, this width is equal to 660-685 mm. For space pressure suits with shoulder bearings the width across the shoulder reaches 750 mm.* Therefore, the width of the cabin must be no less than 800 mm. The required cabin dimensions with respect to height increase by 30-40 mm.

The helmets of space pressure suits, as we had occasion to mention in our examination of the schematic diagrams, are made in large or small volume. To ensure breathing at the ground and low altitudes a window which can be opened is built into the front part of the helmet as a rule, and this window is made to flip down or move up. In some designs with a soft rear wall (not intended for great ram pressures) the entire forward part of the helmet moves up and back. The large-volume helmets are attached to the shell of the space pressure suit permanently by means of a release ring with catches. In such a helmet a pilot is capable of moving his head freely in the required direction, even if he is wearing a mask. The small-volume helmets (Fig. 195a, b) are mounted on a joint with an airtight bearing and rotate about the pilot's head (see also Fig. 170b).

These helmets have been provided with visors which move upward. The movable light filters for the helmets are situated over the visors. In the case of the helmet produced by the Goodrich Company the visor is moved into the helmet; a soft hinged joint in the neck region makes it possible to execute slight forward and back movements of the head.

In designing a helmet for a space pressure suit without a mask the designer encounters the same contradictions as met in the design of airtight helmets for VKK [high-altitude G suits]. The essence of these problems involves the combination of a low oxygen flow rate and a low carbon-dioxide content in the expired air with good ventilation and cooling of the head. Figure 195d [sic] shows one of the contemporary American helmets in whose design an attempt has been made to resolve these contradictory requirements. On the inside the helmet is divided by a face seal into two compartments. The forward compartment is always filled with oxygen, while the rear compartment is connected to the shell of the pressure suit and is ventilated with air. The helmet is equipped with a visor which can be drawn into the helmet. The sealing of the visor is carried out by means of an inflatable chamber. Since it is held that a space pressure suit is intended for fast climbing aircraft, the addition of air to the inspired oxygen was excluded, thus making it possible to use simplified miniature oxygen equipment. The latter is carried on the left-hand side of the helmet. The oxygen "on-off" valve and the depressurization release for the visor are mounted on the oxygen equipment. The oxygen is supplied through a perforated tube mounted around the visor, thus reducing the fogging over of the plates. On the right-hand side of the helmet there is a lever by means of which it is possible to control the inside straps and soft cushions which are used to change dimensions and to hold the face tight against the seal.

In the face compartment some excess pressure, equal to 25 mm water column, is maintained relative to the pressure in the shell in order to prevent the possible drawing in of air around the edges of the face seal. The expired air passes through the expiration valve in the space pressure suit.

The specific power of the electrical heating required to prevent the fogging of the visor plates is the same as in the case of airtight helmets for high-altitude G suits (see Fig. 186). The radiotelephonic communications link from the helmet is set up by means of telephone and throat mikes or microphones. In the space pressure suit with a mask the microphone is mounted inside the mask. In the space pressure suits without masks the microphone is mounted on a bracket attached to the headset or helmet.

The airtight boots and gloves for the space pressure suit are, as a rule, made removable so that the pilot can fit these as to size. Moreover, it offers a number of operational conveniences, i.e., the putting on of the pressure suit is easier, prior to takeoff it is possible to achieve a certain amount of natural ventilation on the ground, and it is easier to dry the shell and its elements.

The connections for the gloves must be such as to enable the pilot to remove and put on his gloves during flight. This may become necessary to execute any fine manipulations of instrument control. Finger mobility in the gloves is achieved by using thin fabric semi-bent finger shapes, and hinged joints.

A change of pressure in a space pressure suit is achieved automatically by means of a regulator mounted in the shell, generally at the left hip. The characteristic of the regulator is such that below an "altitude" in the cabin of the order of 11,000 m the regulator valve freely releases air from the shell and maintains a pressure in the shell of no more than 0.02 kg/cm^2, providing for a loose shell fit about the body of the pilot. If the "altitude" in the cabin exceeds the indicated 11,000 m, the regulator diaphragm close. the outlet valve and then, regardless of the altitude inside the space pressure suit, maintains a constant absolute pressure.

The equipment for floating and keeping the head above water is generally carried on the straps of the composite parachute suspension system.

The weight of the entire space pressure-suit complex (shell, helmet, boots, and outer clothing), designed for an operating pressure of 0.25 kg/cm^2, may come to 10-15 kg.

The ventilation of the entire body surface and the maintenance of a normal thermal regime are provided by proper distribution of air through the shell and by the thermal insulation of the latter.

Space Pressure-Suit Operation*

In order for a space pressure suit to be convenient and for the forces required for movement to be small, space pressure suits are sewn in various sizes for individual fit. The complete putting on of a space pressure suit generally requires the aid of an additional person and takes about 10 minutes.

For normal operation of a space pressure suit it is necessary to have special equipment, i.e., an air-conditioning system aboard the aircraft and ground air conditioners for pilot ventilation during the period he has the space pressure suit on at the ground.

Before flying in a space pressure suit, pilots must carefully study its construction and undergo training in a pressure chamber. Each pilot is responsible for checking out all automatic operations required to close or open the visor, to control the pressure in the space pressure suit, to remove and put on gloves, etc.

Selection of Ventilation Magnitudes for a Space Pressure Suit

The ventilation required for a space pressure suit is chosen on the basis of the permissible concentration of carbon dioxide and water vapors and from the standpoint of providing the temperature regime in the shell and helmet [30].

The permissible carbon-dioxide concentration determines the volume of the oxygen-air mixture which must be supplied over a period of 1 minute to the helmet of a space pressure suit without a mask (we have in mind the fixed helmet with a large free volume).

According to the physiological-hygienic norms, the partial CO_2 pressure in the inspired air cannot exceed 12 mm Hg (at any altitude). The calculation is carried out in accordance with the following formula*

$$v_v = \frac{R_{CO_2} T}{p_{CO_2\,dop}} (q_p + q_l) \text{ l/min}, \qquad (307)$$

where v_v is the required volumetric ventilation of the helmet, in liters per minute; $p_{CO_2\,dop}$ is the permissible partial CO_2 pressure, in mm Hg; q_p is the quantity of carbon dioxide (by weight) in the supplied gas; q_l is the quantity of carbon dioxide liberated by the pilot, in g/min; T is the temperature of the gas in the helmet, in $^{\circ}K$.

In our case $q_p = 0$. The gas constant for carbon dioxide is $R_{CO_2} = 19.3$ m/$^{\circ}$C. Let us assume that with moderate work a single individual liberates 0.6 standard liters per minute of CO_2 (see Fig. 168). The specific weight of the CO_2 at $0^{\circ}C$ is equal to 1.977 g/liter. Consequently, the required ventilation at which the partial CO_2 pressure will not exceed 12 mm Hg amounts to

$$v_v = \frac{19{,}3 \cdot 273 \cdot 0{,}6 \cdot 1{,}977 \cdot 726}{12 \cdot 10^4} = 38{,}4 \text{ l/min.}$$

This quantity (rounded off to 40 liters per minute) was assumed earlier in calculating the required oxygen flow rate in the space pressure suit without a mask.

The required space pressure-suit ventilation as a function of the given relative humidity of the air is determined on the basis of the familiar formula

$$v_g = \frac{G_{H_2O}}{\beta/100E - E_a} \ m^3/hr, \qquad (308)$$

where G_{H_2O} is the quantity of water vapors liberated by man, in g/hr; β is the desired relative humidity, in %; E is the absolute humidity for saturated air at the given temperature, in g/m^3; E_a is the absolute humidity of the air supplied to the space pressure suit.

With moderate work and a temperature of the order of 20°C, a man liberates about 80 g/hr of water vapors. The absolute humidity of the air (see the psychrometric tables) at 20°C amounts to 17.8 g/m^3.

The absolute humidity of the compressed atmospheric air above 7 km is virtually equal to zero. For good flushing of water vapors out of the shell of the space pressure suit, it is suggested that the relative humidity be of the order of 30%. Substituting these initial data into Formula (308), we will obtain

$$v_g = \frac{80}{\frac{30}{100}17.8} = 15 \ m^3/hr = 204 \ l/min.$$

It is held that in order to achieve comfortable conditions in a space pressure suit of the ventilation type, 150-200 liters of air per minute must be supplied (referred to ground conditions). For normal sensation of warmth the temperature of the supplied air directly at the inlet to the shell must correspond to the curve shown in Fig. 203. At a cabin temperature of +50-60°C the air must exhibit a temperature of +10-5°C; if the temperature in the cabin is reduced to −50°C, the temperature of the supplied air must rise to +80°C. This does not mean that air at this temperature stagnates about the human body. Until this air comes into contact with the skin, the air temperature drops as a result of heat transfer from the surface of the tubing and panels of the ventilation system.

§7. PROTECTION OF MAN AGAINST THE EFFECTS OF LOW AND HIGH TEMPERATURES, RADIANT ENERGY, AND EXCESSIVE COLD IN WATER

Operational Conditions and Extreme Temperature Regimes

The crew of an aircraft is subject to the action of a great variety of frequently extremely varied climatic conditions, since during the course of a single flight the following operational situations are possible:

1) anticipation of takeoff at an airfield;

2) flight in a pressurized or depressurized cabin;

3) parachute descent from the upper layers of the atmosphere;

4) emergency landing in open water, with the temperature of the water about 0°C or landing in an Arctic region.

The first two phases of a flight are standard. There may be southern and polar airfields at which the air temperature at the ground ranges from +50 to −60°C.

During the period of the takeoff the temperature in the cabin of a multiseat aircraft is close to the ground temperature as a result of the thermal inertia of the cabin.

The air temperature in a pressurized cabin of an aircraft operating at subsonic speeds, with the air-conditioning system functioning normally, generally ranges from 15 to 25°C. However, with transition to supersonic flight velocities the primary source of cabin heat is the aerodynamic heating of the aircraft surface.

The sun's rays enter the cabin through the upper transparent windows at a rate of 800 kcal/hr for each square meter of horizontal can-

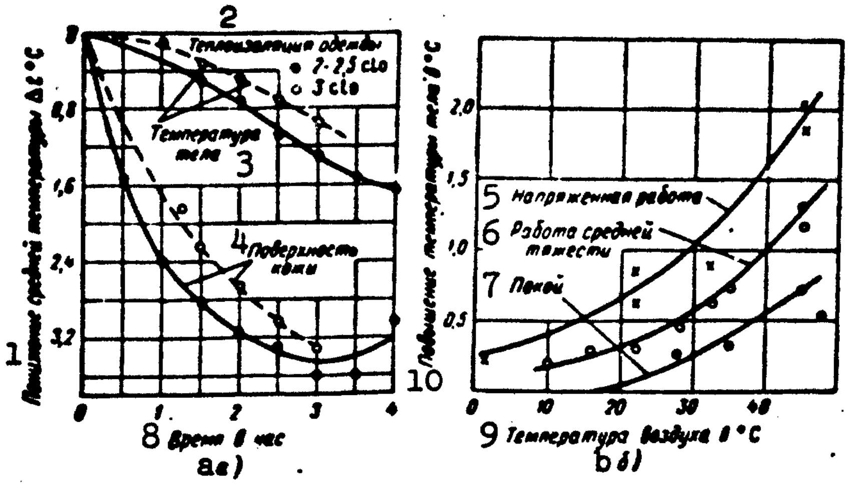


Fig. 196. Change in human body temperature at low and high outside-air temperatures. a) Drop in body temperature for man wearing flight clothing and seated, the outside temperature ranging from −12.2° to −17.7°C:

$$1 \text{ clo} = 0.18\ ^{\circ}\text{C}/(\text{kcal/m}^2\cdot\text{hr});$$

b) rise in body temperature for man engaged in various forms of physical work. The body temperature is recorded after 15 minutes of work and an over-all period of 40-60 minutes. 1) Drop in mean temperature Δt °C; 2) thermally insulated clothing; 3) body temperature; 4) skin surface; 5) heavy work; 6) medium work; 7) rest; 8) time in hours; 9) air temperature, in °C; 10) rise in body temperature, in °C.

opy projection.

The temperature conditions in a depressurized cabin may vary depending on altitude and flight velocity. At subsonic flight speeds and failure of the air-conditioning system, at an altitude of 10-20 km the temperature in the cabin may drop to −30 to −40°C and lower. Calculations show that at velocities corresponding to M = 3, all other conditions being equal, the skin temperature reaches 400°C and the air temperature in the cabin may rise to +70 to +80°C [4].

The temperature conditions during a parachute descent are well known.

In cold water a human being faces the danger of death due to extreme cold. At water temperatures of 0-5°C people who have not been trained to survive in cold water will, within several minutes, exhibit phenomena of cold shock with loss of consciousness. Strong individuals and those trained to withstand the cold will lose consciousness within 20-25 minutes at a water temperature of 0° and within 40-50 minutes at a temperature of 10°.

Extreme exposure of the head and particularly the occipital region to cold is especially dangerous. Biological death occurs when the body temperature drops to 25-22°C. Even if the water temperature is of the order of 15°C, the cooling of the organism continues, and although slowly, within 3-5 hours the victim experiences headaches, drowsiness, convulsions, and finally, loss of consciousness.

Figure 196 shows graphs which indicate the influence of low and high ambient-air temperatures on the human organism.

The curves in Fig. 196a show how the average body temperature and the temperature of the skin surface of a human being sitting quietly in the cold (without wind) diminish if he is clothed in warm flight clothing.* The control of body heat is rather rapidly disrupted and within 1.5-2 hours an individual is no longer able to function normally.

It should be pointed out that the change in the temperature of individual portions of the body is by no means identical (see Table 20).

The data shown in Table 20 confirm that particular attention must be devoted to the thermal insulation of the legs.

Figure 196b shows a rise in body temperature as a function of the ambient-air temperature and the intensity of work.** At an air temperature of +45°C and medium work the body temperature rises by 1.3°, i.e., it reaches 38°C which, as is well known, indicates a sick organism.

The human body liberates the heat formed in the organism as a result of metabolism in the following ways (at t = 20°C):

convection (conduction)........................ 31%
radiation...................................... 43.7%
evaporation.................................... 21.7%

TABLE 20

Change in Temperature at Individual Points of the Body at Rest after Two Hours at a Temperature of +10 and +45°C (after data from N.K. Vitte)

1 Место измерения	2 Изменение температуры в °C	
	3 При t воздуха +10°C	3 При t воздуха +45° C
4 В подмышечной ямке	±0,1	+0,72
5 В кисти руки, зажатой в кулак	−7,0	+6,4
6 В подколенной ямке	−4,6	+6,5
7 В стопе (между пальцами ног)	−10,2	+13

1) Point of measurement; 2) change in temperature, in °C; 3) at an air temperature t of; 4) at the armpit; 5) at the hand, clenched into a fist; 6) at the back of the knee; 7) at the foot (between the toes).

(the remainder is expended to heat food, water, and the air in the lungs).

The thermal regime in which no more than 50% of the total loss of heat is attributable to the transfer of heat as a result of evaporation is regarded as normal.

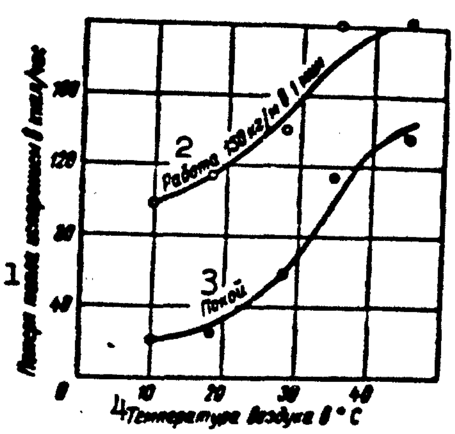


Fig. 197. Loss of heat by human body as a result of evaporation as a function of air temperature. 1) Loss of heat due to evaporation, in kcal/hr; 2) work of 130 kg/m in 1 minute; 3) at rest; 4) air temperature, in °C.

The organism uses convection and radiation not only to liberate heat, but under certain conditions (when the ambient temperature is above the body temperature) the body takes on heat from the outside medium. In the latter case, the control of heat can be achieved only through evaporation.

Figure 197 shows the quantity of heat which the body loses by evaporation as a function of the temperature of the ambient medium at a speed of air motion less than 0.2 m/sec. With intense work the heat output of a human being and the quantity of released moisture may be significantly higher (see Fig. 168). Therefore, if there are no other means of reducing the ambient-air temperature, all of the body-liberated moisture must be evaporated, thus facilitating the organism's maintenance of normal temperature. An optimum ventilation regime must be chosen such that perspiration does not accumulate in the form of drops and simultaneously there should be no sensation of excessive cold. In this case, the loss of weight on the part of the organism will be kept to a minimum.

The complexity of developing individual equipment is a result of the fact that it is necessary during the course of a single flight to protect the individual against both extremely low and extremely high temperatures. This problem is regarded as insoluble only in terms of the selection of the optimum thermal insulation, since a human being will unavoidably experience excessive heat under certain conditions and excessive cold under others.

It is the opinion of foreign specialists that the problem would best be resolved by the establishment of a microclimate zone about the individual by means of ventilated clothing fed with dry conditioned air from ground and on-board installations.

This type of ventilated clothing includes the high-altitude space pressure suit. Moreover, the addition of a thermally insulated layer turns the space pressure suit into a reliable means for water survival and protection against excessive cold in the water.

When a high-altitude G suit is used, ventilated and thermally insulated clothing is put on over this suit when necessary, and when flying over water a waterproof sea survival suit is put on over all of the clothing beneath. Depending on the specific operational conditions and the geographic region in which the flights are being carried out, the above-enumerated protective means are used simultaneously or separately, or in some combination with one another. If necessary, the appropriate suits may be connected into a single suit. A suit of this type exhibits an advantage in terms of the time required to put it on.

The Ventilated Suit

The primary purpose of a ventilated suit is to protect the individual against heat and to remove the moisture vaporized at the surface of the skin. It is natural that the suit must be continuously supplied with air. The required quantity of air comes to 250-400 liters per minute, and the temperature of this air must correspond approximately to the curve (see Fig. 203).

A well-ventilated suit must satisfy the following basic requirements:

1) it must ensure uniform ventilation of all portions of the body, keeping the skin surface in a dry state, and it should produce no local overheating or supercooling;

2) it should not restrict movement, it should be soft and flexible, and the suit should exert no painful pressure against the body;

3) the suit must exhibit low hydraulic resistance.

The simplest ventilated suit can be presented in the form of a system of perforated tubes 6-8 mm in diameter, positioned between the under and outer clothing of the individual. In practical terms, it is convenient to fasten the tubes to the inside surface of the outer clothing. In the case of a space pressure suit or a water survival suit this involves a thermally insulated suit put on beneath the airtight shell.

A drawback of this form of clothing (with a small number of tubes) may be the ununiform ventilation of the entire body surface and high hydraulic resistance. With a large number of parallel tubes it is possible to achieve low resistance; however, as a result there is an increase in the rigidity and weight of the suit.

An individual ventilated suit generally consists of two layers of thin fabric. There are a number of small openings 1.5-2 mm in diameter on the inside (facing the body) layer and the ventilation air sweeps the body through these openings. Flexible pads providing passage for the air in all required directions are situated between the two layers of fabric, and there are round elastic spaces with large openings which connect the inside and outside fabric of the suit. These openings, covering the entire surface and spaced about 100 mm apart serve to carry away the waste air to the outside. The suit does not restrict movement, since it has been provided with a number of openings which are also used to lead in the hoses of the G and antigravity suits.

A shortcoming of a soft suit (without body tubing) is the instability of air distribution for various body positions, i.e., standing, seated, and particularly when the straps of the parachute suspension system are tightened.

The optimum ventilated suit apparently must be a combination of several suits and in addition to ventilated panels and soft channels it must also have a system of branched tubing. The former ensures low hydraulic resistance, while the latter maintains relative stability of air distribution.

Thermally Insulated Suits

A thermally insulated suit must provide for the thermal stability of the human organism under Arctic conditions and in ice water. A man wearing airtight and thermally insulated clothing liberates as much heat to water for which $t = 0^{\circ}$ as is liberated in open air at minus 20-30°C. At the same time, the pilot must be ensured convenience of operation in flight, and the protection of the arms and legs against cold should not restrict freedom of movement.

The materials used for a thermally insulated suit must be light, elastic, nonhygroscopic, and they must exhibit low thermal conductivity. It is desirable for the fabric to be flameproof. We know that fabrics with the thickest possible interlayers of air or air pockets exhibit the lowest thermal conductivity. Good material must be elastic, i.e., its compartments should not produce residual deformation under the action of external forces. Of the materials of organic origin, preference should be given to felt made of deer combings. The shortcoming of this material is sorbtional moisture absorption. Great future promise is shown by such synthetic materials as foam rubber with closed or open air pores. Material of this type, in addition to exhibiting outstanding thermal insulation properties, absorbs little moisture, dries easily, and cannot rot.

Table 21 shows the characteristics of some thermal-insulation materials.

For a comparative evaluation of thermal-insulation materials used for purposes of clothing, specialized foreign literature recently published a new concept, i.e., a unit of thermal insulation, the clo. The magnitude of this unit is set so that it corresponds to the insulation provided by conventional clothing (i.e., a suit and underwear) at room temperature of 20°C and an air-circulation velocity of 0.1 m/sec.

Under these conditions

$$1 \text{ clo} = 0.18\ {}^{\circ}\mathrm{C}/(\mathrm{kcal/m^2 \cdot hr}), \qquad (309)$$

(the thermal resistance of the air interlayer between the body and the clothing is not included in this quantity).

A thermally insulated suit is generally sewn in the form of a complete pair of overalls.

To facilitate movement, the suit is provided with slits. The insulating material is not used at points of contact and where bending

TABLE 21

Basic Characteristics of Certain Heat-Insulation Materials

A № по пор.	B Наименование изоляции	C Коэффициент теплопроводности ккал/м час °C	D Удельный вес кг/м³	E Влагопоглощение за 16 час. %	F Влагоотдача за 8 час. %
1	G Войлок из натуральных шерстяных очесов	0,031—0,035	100—160	23	93
2	Резина оназот мягкий H	0,05	160—200	0,3	67
3	Резина кваэлитексная I	0,05—0,06	100—150	12	95
4	J Искусственные материалы с замкнутыми порами	0,03—0,04	80—120	0,3	67
5	K Поролон (Porella) с открытыми порами	0,036—0,04	35—60	7—9	98
6	L Альфолевая изоляция с воздушными прослойками (для жестких конструкций)	0,034—0,05	40—60	M около 8	M около 100

A) Item No.; B) designation of insulation; C) coefficient of thermal conductivity, kcal/m·hr°C; D) specific weight, kg/m³; E) moisture absorption in 16 hours, in %; F) moisture liberated in 8 hours, in %; G) felt of natural wool combings; H) soft spongy ebonite rubber; I) kvaliteks [sic] rubber; J) synthetic materials with closed pores; K) Porelia with open pores; L) Alfol [aluminum foil] insulation with air interlayers (for rigid designs); M) about.

occurs (for example, at the armpits and knees).

The thermally insulated suit is put on over the ventilated suit, thus achieving higher efficiency for the latter. To reduce radiative heat transfer, the surface of the thermally insulated suit is occasionally made of aluminized fabric which exhibits a low emissivity.

Figure 198 shows a space pressure suit with outer protective clothing made of aluminized fabric providing protection not only against radiant energy but against flames in the case of a fire aboard the aircraft (for a period of 10 seconds). The suit is structurally linked with the suspension system of the parachute whose straps are sewn to the outside shell. According to literature data* the equipment complex shown in the photograph was tested at a temperature of +77°C and for strength at the pressure of an airstream moving at 1200 km/hr (indicated).

Fig. 198. Outside protective suit of aluminized fabric with parachute suspension system sewn in and worn over G suit or space pressure suit.

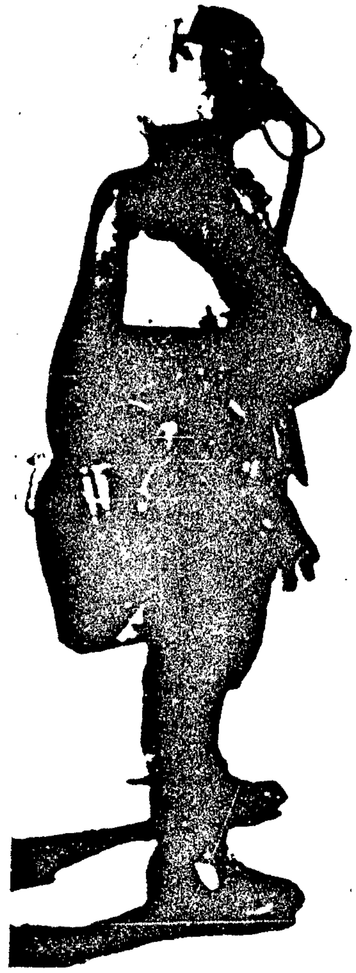


Fig. 199. Pilot in water survival suit and protective helmet with parachute backpack and emergency survival kit. Valves for release of ventilation air can be seen on sleeves and pants.

Water Survival Suits*

A water survival suit must:

1) be waterproof;

2) exhibit the capacity to float and provide for a body position at which the head is above the water level;

3) be equipped with devices for turning the pilot's face upward automatically and for the rapid filling of life preserver or vest;

4) make possible comfortable working and free movement;

5) protect the individual against excessive heat and cold.

The last requirement is achieved by using the above-described ventilation and thermally insulated clothing in conjunction with the waterproof water survival suit.

Figure 199 shows a water survival suit. This suit together with the underwear, the ventilated and insulated clothing, provides thermal insulation equal to 3 clo (including the 1.5 clo provided by the thermally insulated suit). The clothing complex provides thermal protection and normal conditions for the individual under the following conditions: in ice water, no less than 2 hours; at an air temperature of $-35^{\circ}C$, 1 hour; at an air temperature of $-1^{\circ}C$, for an unlimited period of time.

By making the thermal insulation thicker it is possible to increase these time periods.

At a cabin temperature of +15 to $+20^{\circ}C$ and higher it is unhygienic to use such a suit without ventilation.

It should be borne in mind that the air interlayers between the thermally insulated and waterproof suits significantly increase the heat-protection properties.

Four valves — one each on the sleeves and on the pant legs — are provided on the outside waterproof shell (see Fig. 199). The valves are opened by the discharge air and are closed by a spring as soon as the air flow ceases. The installation of several valves provides for a reduction in the resistance of the ventilation system and for the uniform distribution of the air over the entire body.

Air is fed into the suit through a flexible hose fitted out with a fast-release sleeve which has a return-flow valve to prevent the entry of water into the inside cavity of the suit.

A V-shaped opening edged with a zipper is provided to permit donning of the suit.

The penetration of water into the suit is blocked by the "appendix" (Fig. 200). When open, the appendix provides a large opening through which the suit can be put on easily.

The suit is kept airtight at the neck and wrists by means of elastic rubber valves. To protect the arms against cold, use is made of waterproof gloves with halfbent fingers, providing for better thermal insulation due to the more uniform air interlayer.

Fig. 200. Opening with "appendix" in sea survival suit.

Fig. 201. Life preserver vest with collar and "gills" for stable upward position of head.

In order to maintain the required floating position such that the head and occipital region are adequately lifted out of the water, the suit is equipped with a floating collar and there are additional sacks – "gills" – which fold under the armpits when not inflated, and these provide for stable position. Generally the two devices are incorporated into a life preserver (Fig. 201). The life preserver is filled with carbon dioxide from a special tank carried together with the suit. The tank may be operated either manually or automatically. The latter becomes necessary if the pilot falls into the water in an unconscious state.

One of the possible designs for a mechanism to ensure the automatic actuation of the carbon-dioxide tank involves a frame in which

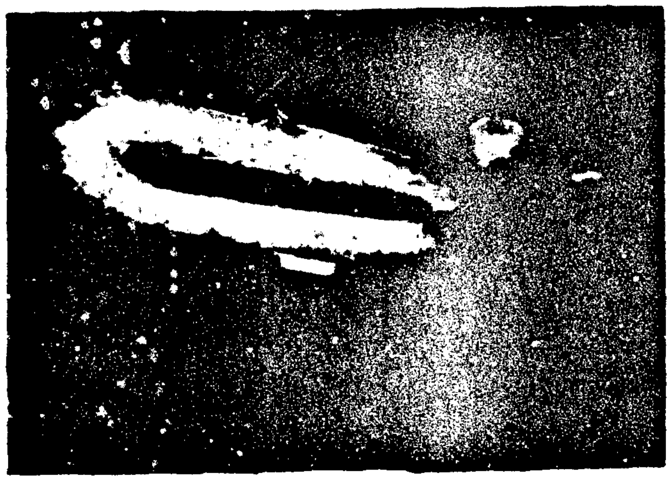


Fig. 202. One-man inflatable raft contained in Navy pilot's portable emergency kit (USA).

there is a piston, a spring-operated plunger, a rubber flap valve, and a chemical tablet consisting of 60% tartaric acid and 40% bicarbonate of soda. In water, the latter passes through the valve, softens, and dissolves the tablet, as a result of which a gas is formed. The pressure of the gas closes the rubber valve and sets the plunger into motion, and this in turn operates the spring-driven plunger, the latter lowering the pin of the mechanism to pierce the membrane of the carbon-dioxide tank. As a result, the life preserver is filled. The device operates within 15 seconds after hitting the water and weighs about 0.15 kg.

The water survival suit is generally used in combination with some type of high-altitude equipment such as, for example, the airtight helmet of a high-altitude G suit or a protective helmet.

To protect the head against the entry of water into the helmet and also to provide protection against excessive cold while at the same time ensuring breathing is regarded as a difficult problem. It is held possible to design a device to attach to the helmet, which would pass air but would block the entry of water into the breathing units. In the absence of such a device it is necessary to use the inflatable raft which is included as part of the equipment in the portable emergency kit (Fig. 202).

A shortcoming of existing airtight helmets, as indicated in foreign literature, is the unsatisfactory ventilation of head and face, since the oxygen supply provided by the automatic lung is inadequate to remove all of the heat. If it is particularly hot, perspiration blocks vision and hampers work. An increase in the oxygen flow rate would provide good results, but this would significantly raise the weight of the aircraft structure.

To reduce the heating of the head resulting from solar radiation and the emission of the cabin walls, helmets are coated with a light paint of low emissivity. Thermal insulation is provided on the inside of the helmets.

Conditioned Air for Ventilated G Suits and Space Pressure Suits*

In order to ensure hygienic conditions, a space pressure suit, a water survival suit, or an individual ventilated suit must be continuously ventilated.

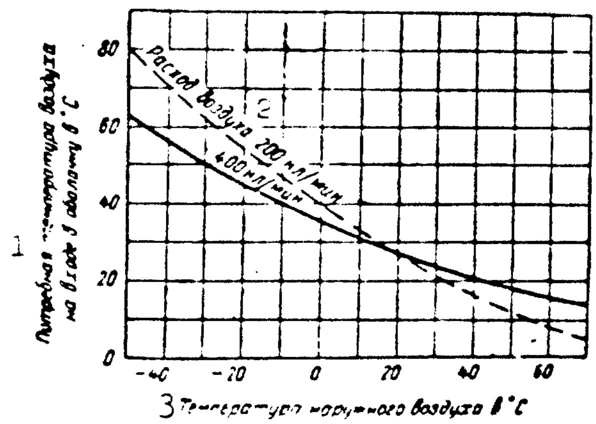
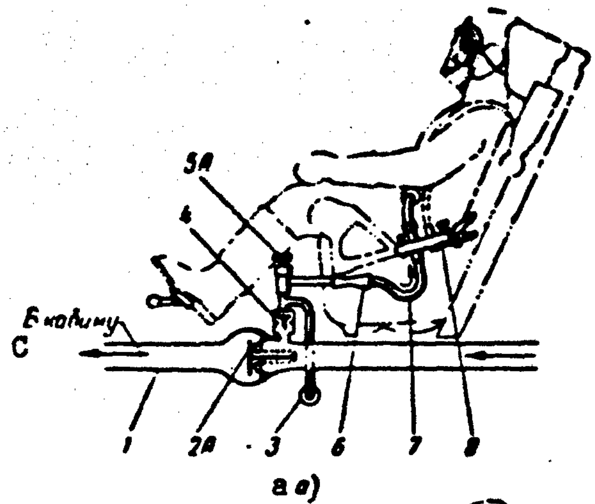


Fig. 203. Required air temperature at inlet to protective clothing as a function of ambient temperature. 1) Required air temperature at inlet to shell, in °C; 2) air flow rate, 200 standard liters per minute; 3) ambient air temperature, in °C.

With an outside air temperature of −10 to +10°C the minimum required ventilation may be 80-100 standard liters per minute. As the



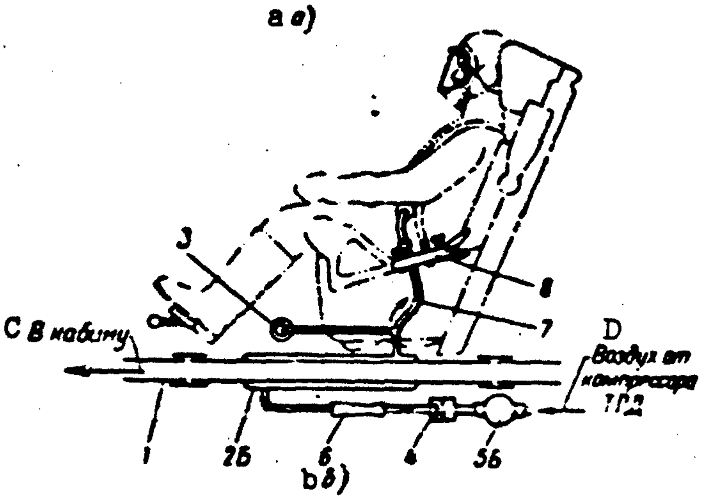


Fig. 204. Diagrams of ventilation of protective clothing employing cabin climatization systems employed in foreign aircraft. a) For a cabin without turbine-operated cooling unit; b) for cabins cooled with turbine-operated cooling units. 1) Air line; 2A) support valve; 2B) heat exchanger; 3) connection tube for ground ventilation; 4) return-flow valve; 5A) valve; 5B) air-feed regulator; 6) metering tube; 7) flexible hose; 8) consolidated release. C) To cabin; D) air from TRD [turbojet engine] compressor. A = A; Б = B.

range of the ambient temperature increases, the supply of air that is required increases and in the case of space pressure suits and water survival suits amounts to 200-250 standard liters per minute, while for independent ventilated clothing the requirement is 350-400 standard liters per minute.

Figure 203 shows an approximate relationship between the required temperature of the ventilated air at the inlet to the protective clothing and the outside temperature. The disposable air pressure difference across the inlet to the clothing must be equal to the hydraulic resistance of the suit's ventilation system for a given air flow rate.

This resistance for contemporary equipment amounts approximately to 0.2 kg/cm^2 for an air flow rate of 200 standard liters per minute and varies quadratically for other values of the air flow rate.

Depending on the resistance of the on-board tubing and the excess pressure in the space pressure suit at high altitudes, the required air pressure head correspondingly increases to 0.6 kg/cm^2.

The supply of conditioned air for the protective clothing may be achieved by:

1) taking climatized air from the tubes of the cabin climatization system (Fig. 204a);

2) the installation in the aircraft of an autonomous air conditioning system for clothing (see Fig. 205);

3) the utilization of an installation which uses the heat and cold sources of the cabin system, but which has an independent system for the automatic regulation of air temperature.

In the majority of aircraft the available head in the tubing of the cabin blower system (behind the turbine-operated cooler installation) is inadequate to provide for the ventilation of the protective clothing, and even more so of the space pressure suits. Therefore, additional installations are required. Two possible versions of such installations are shown in Fig. 204.

The diagram in Fig. 204a shows a simple spring disk valve mounted in the tubing of the cabin blower system which opens as air passes, i.e., a so-called support valve. The operation principle for this valve is analogous to that of the dam in the case of a water mill.

In front of the support [bleeder] valve there is a connection tube from which air is taken for the ventilation of the clothing. The

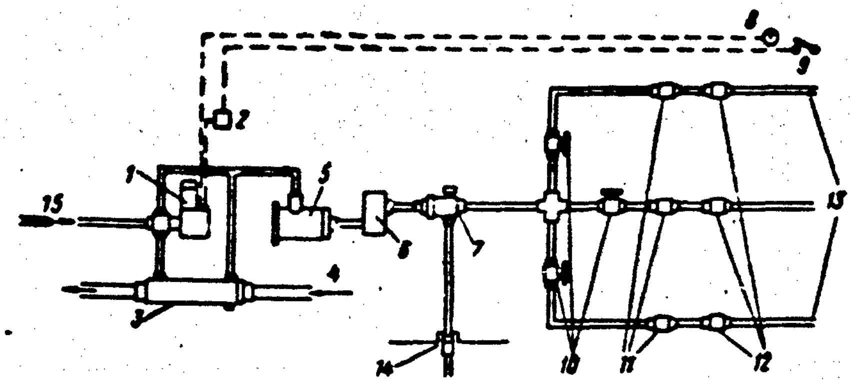


Fig. 205. Air-conditioning system for ventilated suits aboard the "Canberra" aircraft. 1) Selector valve; 2) command transmission mechanism; 3) heat exchanger; 4) fuel [combustible] supply to engine; 5) moisture dryer; 6) air flow-rate regulator (maximum feed limiter); 7) return-flow valve; 8) selector position indicator; 9) switch; 10) manual cocks; 11) fast-release connections on seats; 12) fast-release connections (sleeves) on suit; 13) air tubing to suits; 14) connection tube for linking of ground conditioning equipment; 15) tubing from engine compressor.

monitoring of the quantity of air is carried out by means of a flow-rate indicator which measures the pressure difference between the narrow and wide sections of the metering tube.

The basic element of the design shown in Fig. 204b is the heat exchanger (in the form of a jacket) mounted in the tubing of the cabin blower system. This approach is expedient because it exerts absolutely no influence on the hydraulic resistance of the cabin blower system, while at the same time making it possible to achieve a high available head at the inlet to the protective clothing. The ventilation air is taken from the engine compressor, it passes through the feed regulator 5B, and enters the heat exchanger 2B where it is heated or cooled. From the heat exchanger 2B through hose 7 and the consolidated release 8 mounted on the seat, the air enters into the suit.

A shortcoming of these two described versions, as indicated by foreign specialists, is the fact that under certain operational regimes there may occur a certain "mismatch" between the temperatures of the air fed into the cabin and into the suit. In this case, the pilot will experience either excessive heat or excessive cold and will have to reduce the supply of air manually.

Provision has been made in both designs for an on-board connection tube to be employed for the ventilation of clothing on the ground by means of a portable ground air conditioner.

Figure 205 shows an air-conditioning system developed by the English firm "Godfrey" for the ventilation of clothing, used aboard "Canberra" aircraft which operate in tropical regions. The system is designed for the ventilation of a crew consisting of 3 men and yields a supply of 40 m^3/hr of air at an excess pressure of 0.5 kg/cm^2 (i.e., about 225 liters per minute for a single individual).

The heat exchanger mounted in the main kerosene fuel line is used to cool the air. The air taken from the engine compressor through the selector-distributor 1 passes into the system either through heat exchanger 3 or directly. Then the air passes through drier 5 and maximum-feed limiter 6 into the tubes connected to the work positions of the crew. Each pilot is provided with a manual stopcock 10 to control the quantity of air as a function of individual sensation of heat. The selector valve 1 controlled from the cabin makes it possible to obtain air of the desired temperature by redistributing the quantity of air passing through the heat exchanger or bypassing it. The connection tube of the ground ventilation 14 is connected to the main system through a T-connection which is fitted out with a return-flow valve 7.

Foreign scientists propose various versions and refinements of this design. They hold that the operation of the distributor valve must, first of all, be automated in accordance with the required air temperature. This can be achieved in two ways: i.e., by the installation of a temperature sensing element beneath the shell or by the installation of two sensing elements — one in the tubing, behind the distributor, and a second, in the air of the cabin in order to provide for automatic correction for heat transfer on the part of the tubing. The first method, in their opinion, is inferior with respect to the fact that excess electrical connections are required to link the pilot with the inboard facilities of the aircraft, and because of the interchangeability of the sensing elements with the temperature regulators.

It is held that other sources of cold may be used in an aircraft. In particular, the heat exchanger need not be installed in the fuel manifold, but can be mounted on the tubing of the cabin blower system, behind the turbine-operated cooling unit. It is also possible to install an individual turbine-operated cooling unit designed especially for the ventilation of the protective clothing.

For purposes of ventilating people wearing protective clothing it is held necessary to use ground air-conditioning installations.

There are two types of such installations, e.g., with an air cycle (i.e., with a turbine-operated cooling unit) and a compression-vapor cycle (with an evaporating cooling agent, as in home refrigerators). The first type of installation is generally designed for large air flow rates with a low head and is used primarily for ventilation and cooling of aircraft cabins.

Ground air conditioners working with a compression-vapor cycle xhibit smaller dimensions and are used for the supply of cool dry air o the ventilated suits. This type of installation (produced by the ritish firm "Godfrey") produces 35 m^3/min of air at a discharge presure of up to 0.7 kg/cm^2 (at the indicated flow rate). The installaion is mounted on a two-wheeled car trailer.

It is convenient to use buses equipped with such an air-condition- system at airfields to transport pilots. The tubing is connected each seat in the bus.*

Protection Against Cosmic Rays

We can arrive at relatively reliable assumptions as to the results of prolonged exposure of the human organism to cosmic radiation in analogy with the effect of ionizing radiations obtained in laboratories.

The biological effect of radiation depends not only on quantity,

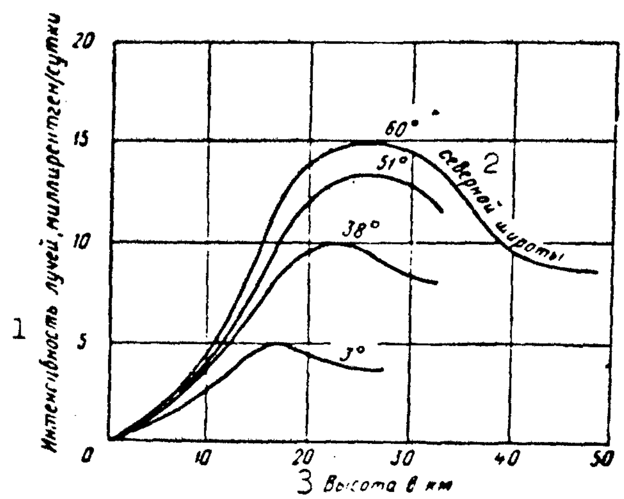


Fig. 206. Intensity of cosmic radiation (expressed in physical equivalents of the roentgen) as a function of altitude and geographic latitude. 1) Intensity of rays, milliroentgens per day; 2) north latitude; 3) altitude, in km.

but on the nature and characteristics of the rays. Thus, for example, the harmful effect on the organism of γ-rays is smaller by a factor of 10 than that of α-particles and smaller by a factor of 20 than the fast neutrons whose energy exceeds 20 million electron volts.

The following radiation tolerances (in physical equivalents of roentgens) have been established in the Soviet Union: 0.05 roentgens per day (more exactly, during a single work day) and no more than 0.3 roentgens per week, if it is difficult to control the daily dosage [11]. On the whole these norms correspond to the recommendations of the International Radiological Congress held in London in 1950.

A single exposure to 50-100 roentgens can be tolerated.

The ionizing capacity of cosmic rays is greater by a factor of about 10 than the effect of γ-rays and therefore the permissible dosage of the former must be smaller by a factor of 10.

Figure 206 shows the results obtained by Milliken in the measurement of the ionizing effect of cosmic rays at various geographic latitudes, expressed in physical equivalents of the roentgen. From these curves we can see that in the middle latitudes (50-60°) at altitudes of 20-30 km the maximum radiation dosage is 13-15 milliroentgens per day, whereas in the case of regular irradiation the limit dosage should be set at 5 milliroentgens per day.

At the present time aircraft fly for several minutes at high altitudes and pilots need fear no harmful effect from cosmic radiation.* However, future astronauts, in the opinion of foreign scientists, will have to contend on a more serious level with protection against cosmic radiation, and from the engineering standpoint the problem is difficult. Nevertheless, it is possible to protect the most sensitive portions of the human organism against radiation, thus raising the permissible level of radiation dosage.** In the opinion of foreign scientists this can be achieved by using light filters made of silica glass containing large quantities of lead to protect the eyes, and by incorporating lead strips in the clothing to protect the region of the neck lymph nodes, the heart, the spleen, and the gonads. In seeking the solution to this problem it should be borne in mind that in the presence of high-energy particles excessively thin screening may result in a cascade of secondary particles which, in turn, produce a harmful effect.

The curves shown in Fig. 206 show that at altitudes below 40 km the intensity of primary cosmic radiation increases toward the terrestrial poles. This phenomenon is brought about by the fact that the terrestrial magnetic field deflects cosmic rays approaching the earth from outer space toward the magnetic poles. Therefore, if a flight is carried out in the vicinity of the geomagnetic equator at the indicated interval of altitudes, the harmful effect of cosmic radiation may be reduced by a factor of approximately three in comparison with a flight carried out at a latitude of 60°.

§8. PROTECTION OF INDIVIDUAL AGAINST RAM PRESSURE AND DECELERATION G FORCES ON EJECTION

On ejection at great speeds man is subject to the pressure of the approaching free airstream, this pressure proportional to the square of the true speed and the density of the air.

In the case of upward ejection the effect of ram pressure begins as soon as the canopy is jettisoned and the pilot's head rises above the cockpit.

The ram pressure attains its maximum within 0.08-0.14 second, and then diminishes rather rapidly (by a factor of more than 2) during the first second.

The influence of ram pressure on the human organism and on the strength of the equipment is studied in open wind tunnels. Man (or a dummy) is subjected to a sudden airstream; then the velocity is reduced by opening the side bleeder orifices.

In actual flight the seat, after ejection, is immediately decelerated by the air. In this case the acceleration [G forces] is experienced in the "back-chest" direction. The maximum magnitude of these G forces are calculated in accordance with the formula presented in Chapter 5, §10.

We know from foreign sources that the influence of the G forces resulting from linear acceleration is studied on trolleys driven by rocket engines (the so-called rocket sleds) mounted on a special straight track 600 to 6000 m long and equipped with a brake mechanism.

As has already been pointed out, great ram pressure can be withstood because the seat supports all parts of the human body (given the condition that measures have been taken to prevent the flailing of extremities).

Various types and component parts of high-altitude and protective equipment function in a variety of ways under ram-pressure conditions and therefore their protective effect should be examined in separate elements.

Protection of the Pilot's Head. The Protective Helmet

The face is the part of the human body most vulnerable to ram pressure. Below an indicated speed of 750 km/hr (which corresponds to a ram pressure of 2700 kg/m^2) the pressure of the airstream can be withstood without harmful effect. With continued rise in the velocity, the eyes, mouth, nose, and respiratory organs may be damaged.

Fig. 207. Transparent oxygen mask produced by the Scott Aviation Corporation, this mask covering the entire face.

On ejection at great altitudes, a continuous oxygen supply is required in addition to protection of the face against mechanical damage. Therefore, when an oxygen mask is employed the latter must be kept in proper position on the face and the airtight fit must remain intact after cessation of the ram pressure (a period of 2-3 seconds during which airtightness is lost can be tolerated).

Conventional masks with reinforced four-point attachment to a headset can withstand ejection at V_1 = 700-750 km/hr.

Figure 207 shows an experimental rigid transparent mask which covers the entire face. This mask can offer protection against ram pressure at a V_1 on the order of 900-950 km/hr.

Brief ascents to altitudes of 15-16 km are generally carried out in an equipment complex consisting of a G suit, an oxygen mask with

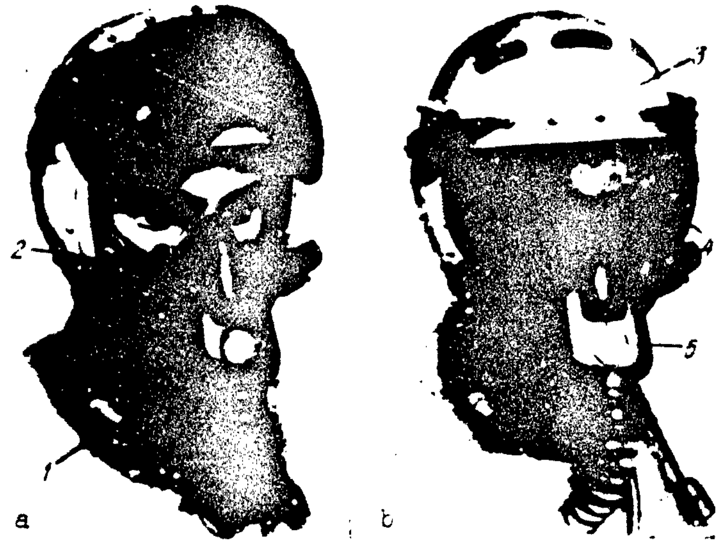


Fig. 208. Protective helmet with oxygen mask used by the USAF and other countries. a) Protective visor, light filter raised; b) protective visor, light filter lowered. 1) Hose to tension compensator of oxygen mask; 2) oxygen-mask release; 3) textolite helmet; 4) protective visor-light filter; 5) oxygen mask.

excess pressure, and a protective helmet.

The protective helmet has several functions: to protect the head and face against being struck accidentally, and to protect the pilot against the blinding effect of solar rays and the ram pressure.

Protective helmets are made in one of the following two versions:

1) a single protective helmet (replacing the helmet headset as well); in this case, the telephones are connected to the helmet on plate springs;

2) an antishock helmet with a movable light filter, worn over a headset.

In the first case the oxygen mask is fastened to the protective helmet, while in the second case it is attached to the headset.

The construction of a protective helmet fabricated in accordance with the first design is clear from Fig. 208.

The helmet portion is stamped from synthetic fiber material such as, for example, glass textolite which imparts the required strength and elasticity to the helmet. The outside surface of the helmet is polished in order to reflect radiated heat, while the inside surface is coated with thermal insulation. A movable light filter made of non-breakable plastic is hinged at two points and attached reliably at the two extreme positions. When the light filter is in the lowered position it serves as an additional means to keep the mask on the face. In this position the permissible ejection velocity is 900-1000 km/hr. The maximum velocity is generally limited by the reliability of oxygen-mask attachments and its airtightness (after the effect of the ram pressure).

The weight of the protective helmet on the average amounts to 2.5 kg.

The airtight helmet of the G suit may protect the head to $V_1 \approx 1100$ km/hr, while space pressure suits can serve this function to $V_1 \approx 1200\text{-}1300$ km/hr.*

Table 22 shows the tolerance values of indicated speed at which various types of equipment for head and face protection may be employed.

The lower permissible velocities for a protective helmet and the airtight helmet of a VKK [high-altitude G suit] in comparison with a space pressure suit can be explained by the fact that the airstream may cause a sharp turning of the head to the side and force it away from the headrest. The rise in the permissible ejection velocity for these types of equipment is associated with the mounting of additional devices on the seat to prevent the shifting of the head.

The utilization of a space pressure suit with a fixed helmet, with its relatively large volume in which visibility is achieved by turning the head inside the helmet, results in other complications on ejection. The ram pressure exerts absolutely no effect on a man's head in such a helmet. Therefore, the inertial forces developed by G forces

TABLE 22

Tolerable Ejection Velocities as Functions of Face-Protection Method Against Ram Pressure*

A № по пор.	B Тип снаряжения	C Допустимая скорость V_1, км/час
1	Маска с шлемофоном D	750—800
2	Маска с защитным шлемом и опущенным светофильтром E	900—950
3	Герметический шлем с компенсирующим костюмом F	1000—1100
4	Высотный скафандр G	1200—1300

*The permissible ejection velocities are presented from translated sources and are tentative. It should be borne in mind that the permissible velocity is a function of helmet design features, its strength margin, and the method by means of which it is connected to the protective clothing and ejection seat.
A) Item No.; B) type of equipment; C) permissible velocity V_1, in km/hr; D) mask with headset; E) mask with protective helmet and lowered light filter; F) airtight helmet with G suit; G) high-altitude space suit.

on deceleration of the seat in the airstream lead to a intense depression of the head forward, and this may result in the face striking against the helmet or the wrenching of the neck vertebrae.

This forward movement of the head is also experienced when the pilot is protected against the ram pressure by the cockpit canopy.

G forces below 25 in the "back-chest" direction are regarded as completely safe for a pilot's head and neck if he is wearing a space pressure suit. At higher G-force values it becomes necessary to resort to special measures in order to prevent the consequences of the head being forced forward, i.e., automatic fixation (tensioning) of the head at the instant of ejection or the "wedging" of the head inside the helmet by means of chambers which inflate automatically.

As reported in the foreign press, some pilots, not wishing to wear airtight helmets, hold that in case of the need for ejection they will first reduce flight velocity. However, it is not an infrequent occurrence that an emergency begins with loss of aircraft control and entry into a dive. It is obvious that in this case it will be impossible to reduce velocity. Under other circumstances, in order to reduce velocity, the pilot will instinctively pull back on the stick and the aircraft will climb to an altitude at which the oxygen mask will no longer be able to ensure retention of consciousness. It is held therefore that aircraft pilots operating at supersonic velocities must use equipment which will provide a certain "coefficient of safety," i.e., to make it possible to use G suits with airtight helmets or space pressure suits.

The Function of the Protective Clothing on Ejection

In addition to its primary function — to provide the necessary pressure in the alveolar air and at the surface of the pilot's body — a high-altitude G suit and the shell of a space pressure suit on ejection also protect man against the effects of ram pressure.

In the case of great ram pressure the specific pressure at certain points of the body may attain extremely high magnitudes.

The purpose of high-altitude clothing (from the standpoint of protection against the airstream) involves the uniform transmission of the resulting stresses over the body or, more exactly, in the development of a stress pattern over the body such that these can be withstood without harm.

In this connection the space pressure suit and other forms of protective clothing vary as to operation.

The shape of a space pressure suit is altered by the action of ram pressure, thus leading to a reduction in the internal volume and to a pronounced increase in the pressure inside the space pressure suit, attaining 80% of the total ram pressure. Of course, a portion of the space pressure-suit shell in this case touches against the body surface and exerts pressure directly; however, an increase in the pressure inside the space pressure suit eases the ability to withstand these stresses.

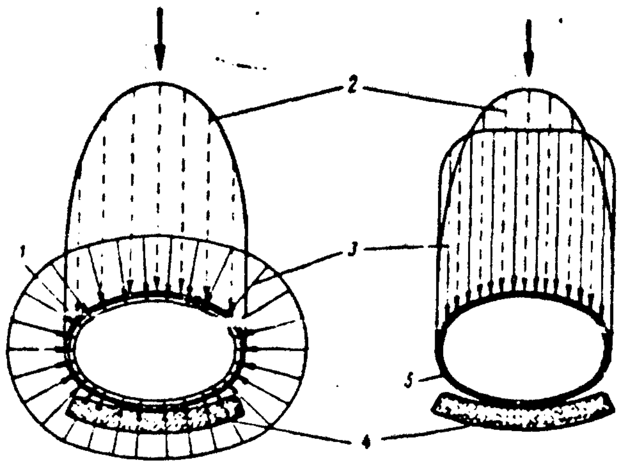


Fig. 209. Idealized diagram of space pressure-suit and G-suit operation in airstream. 1) Shell of space pressure suit; 2) ram pressure against shell; 3) pressure against human body; 4) back of seat; 5) suit.

Let us assume that the space pressure suit is sufficiently strong and that we have filled it prior to ejection to the ram pressure. In this case, a pilot wearing this space pressure suit will be virtually unaware of the airstream pressures.

In all other forms of clothing the redistribution of pressure is achieved exclusively through the work of the clothing fabric itself and it is impossible to achieve the same uniformity of stress distribution as with a space pressure suit. The patterns shown in Fig. 209 illustrate the above-cited concepts.

§9. PROTECTION OF MAN AGAINST EFFECT OF CENTRIPETAL ACCELERATIONS

Effect of acceleration on human organism and methods of reducing its harmful effect

Unlike the ejection process in which the acceleration due to the explosion of the firing cartridge and the acceleration [G forces] due to the deceleration of flight velocity after ejection from the aircraft act on the individual for a period of 0.1-0.2 second, in the case of flight maneuvers accelerations are felt for a rather prolonged period of time, i.e., from several to tens of seconds.

On ejection the short-duration "shock" acceleration (if a certain fixation of the body is not provided for) may lead to purely mechanical damage to internal organs and the spinal column (particularly the lumbar vertebrae). Even slightly prolonged accelerations, although of considerably smaller magnitude than on ejection, reduce the working efficiency of a pilot as a result of a temporary deficiency in the supply of blood to the brain. Subjectively, this may be felt as dimness. The accelerations result in the draining of blood from the head and the chest cavity to the abdominal cavity and the lower extremities. This has been confirmed by experiments on a centrifuge in which an increase in the volume of the shinbone and simultaneous reduction in the volume of the pinna have been detected. The described phenomenon is accompanied by a reduction in blood pressure in the vessels of the brain and an increase in the venous blood pressure at the lower extremities, as well as by a wide range of similar disruptions of circulation regulation.

The foregoing suggests a method of protecting a pilot against the effect of positive acceleration during curvilinear flight.

It is necessary to prevent the drain of blood to the lower extremities, as well as to guard against the shifting and intense filling of the organs in the abdominal cavity with blood. This is achieved by means of antigravity devices (PPU). Before undertaking a description of their design, it is expedient to become familiar with the resistance of an organism to prolonged acceleration. In the conventional vertical working position of a pilot (with a back lean of 15-20°) and the effect of mechanical forces in the "head-pelvis" direction, brief

(1-2 seconds) accelerations below 6 units can, for the most part, be withstood without a noticeable reduction in operational efficiency. Trained pilots are able to withstand satisfactorily accelerations below 7-8 for a fraction of a second and in this case only a few will experience brief dimness. They can also withstand satisfactorily prolonged acceleration below 4-5 units lasting 15-20 seconds. With prolonged acceleration above 5 and with brief acceleration above 8-9 significant functional disturbances generally set in, including brief loss of vision and consciousness.

The antigravity devices raise the tolerance of the organism or, in other words, reduce the harmful effect of acceleration by a factor of about 2.5-3 units. Thus if a 9 G force acts on an aircraft, physiologically the pilot experiences G forces of 6 units. It should be stressed that the protective properties of the antigravity devices may be used only in the case of G forces acting in the "head-pelvis" direction. PPU [antigravity devices] produce no positive effect in the event of instantaneous accelerations in the case of seat ejection.

Design of Antigravity Devices*

The antigravity equipment complex consists of two basic parts:

1) an antigravity suit (Fig. 210) which is an individual piece of equipment for the pilot;

2) a special automatic unit (the so-called pressure automat) which controls the air pressure in the pneumatic chambers of the suit in proportion to the acceleration magnitude.

The automatic pressure unit is fixed in position aboard the aircraft and is supplied with compressed air from the engine compressor.

The antigravity suit exerts mechanical pressure against the lower extremities and the abdomen, and it is made with tensioning devices of the same type as in G suits (see Fig. 181). The magnitude of the air

Fig. 210. General view of antigravity suit as worn by a person.

pressure in the chambers and their geometric dimensions are selected so as to balance the increase in the hydrostatic pressure of the blood in the lower extremities produced by the action of the acceleration.

Figure 211 shows the air pressures in two types of tensioning devices as functions of acceleration magnitude. For a suit made in the form of Fig. 181a (with circular chambers) the required pressure in the case of G forces equal to 10 units amounts to 1.3-1.5 kg/cm^2. For a suit with flat chambers the required pressure is less and with 8 G forces does not exceed 0.65 kg/cm^2. These quantities are the minimum air pressures which the aircraft designer must ensure at the inlet to the PPU automatic unit.

Antigravity suits are made either in the form of a separate suit or structurally combined with a high-altitude G suit. The independent antigravity suits are made either only with flat chambers (see Fig. 210) or with a combination of chambers, and namely: round chambers are included to compress the legs (calves and hips), and a flat chamber to compress the stomach.

In view of the fact that the abdominal chamber has great area and may distend more than necessary upon application of pressure, it has limiter laces on the inside. This makes it possible to apply as much pressure to the abdominal chamber as to the round chambers.

Antigravity suits are generally made of capron or nylon fabric and are produced in 6 sizes. For individual fit about the diameter lacing is passed through eyelets. The suit with flat chambers generally

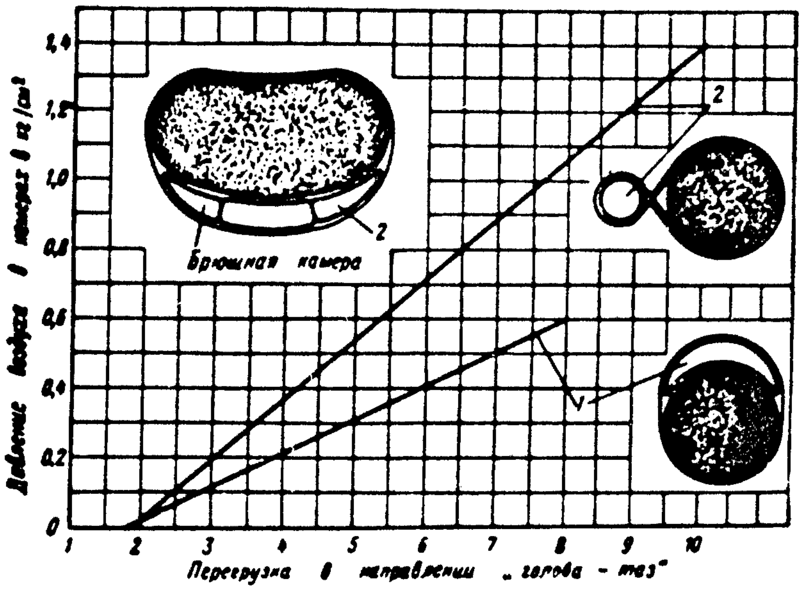


Fig. 211. Required excess air pressure in tensioning chambers of antigravity suit as a function of acceleration magnitude and chamber type: 1) for flat chambers; 2) for round chambers. A) Air pressure in chambers, in kg/cm^2; B) abdominal chamber; C) acceleration in "head-pelvis" direction.

has 5 pneumatic chambers, i.e., one each at the hips, the calves, and at the stomach, fashioned into a single whole. To prevent the chambers from sticking together, a steel spiral in a capron covering case is included on the inside. An antigravity suit weighs about 1.5-2 kg.

The automatic pressure unit in the event of acceleration acts in the "head-pelvis" direction and must maintain a pressure corresponding to the curves shown in Fig. 211 automatically and without delay. A schematic diagram of the automatic pressure unit is shown in Fig. 212. The device consists of frame 1 in which slide valve 2 shifts vertically. Weight 3 presses against the top of the slide valve; in the absence of acceleration the weight is offset by the force of spring 4. In this case, the window of the inlet connection tube 5 is closed by slide valve 2 and no air can enter the suit chamber. The small quantity of air which is drawn in through the clearances between the frame and the slide valve is discharged through special drain orifices that have been provided for in the frame.

At the instant that the acceleration appears, the inertial forces of the weight and slide valve compress spring 4 and force the slide valve down. In this case, a trapezoidal passage in the slide valve opens to permit movement of the compressed air and the latter proceeds into the chamber of the antigravity suit through a hose. A portion of the air passes through an opening in the neck of the slide valve to the lower chamber beneath the slide valve where pressure is developed to raise the slide valve upward. As a result, the slide valve is mounted in some equilibrium position corresponding to the magnitude of the given acceleration and the air leakage losses from the automatic pressure unit.

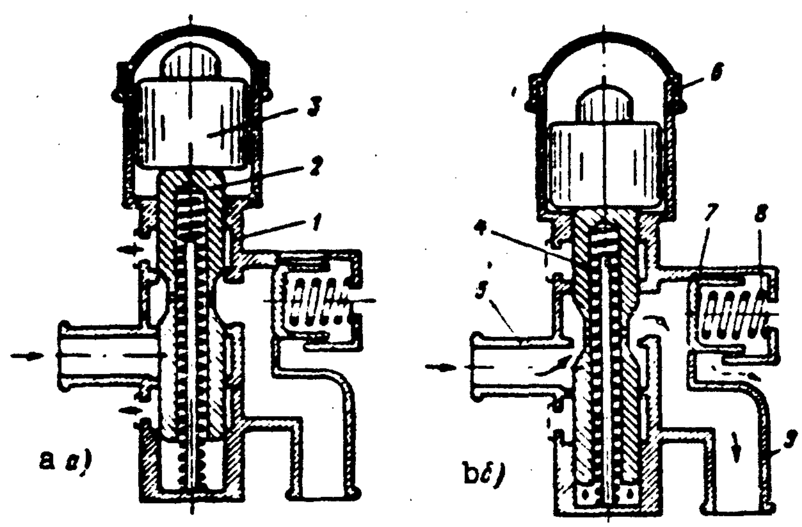


Fig. 212. Diagram and operation of automatic pressure unit in antigravity installation. a) No acceleration; b) with acceleration. 1) Frame; 2) slide valve; 3) weight; 4) spring; 5) inlet connection tube; 6) rubber cap; 7) check valve; 8) spring; 9) connection tube for air discharge into PPK [antigravity suit].

Various characteristics for air pressures developed by the automatic unit (during the design stage of the latter) are obtained by changing the weight and the diameter of the slide valve. There are automatic units in whose design there are two weights, so that the pilot can, at will, use one or both weights by turning the head of the unit. This makes it possible to obtain two different characteristics from a single automatic unit.

Aboard an aircraft the automatic pressure unit is mounted only in the vertical position. For reliable and failproof operation of the device it is necessary for the air entering the unit to be free of dust, moisture, or oil. Therefore, a special filter is mounted in front of the automatic unit and the upper portion of the unit is covered with a soft rubber cap 6 to prevent the entry of contamination between the slide valve and the frame. The cap is made elastic so that after the engine has been started the pilot can check the operation of the automatic unit and his antigravity suit by pressing his finger against the weight.

§10. THE PORTABLE EMERGENCY KIT (NAZ)

In the case of emergency abandonment of an aircraft the members of the crew may find themselves in some uninhabited area. The aircraft may break up, burn, or sink. For this eventuality the survivors must be equipped with facilities to signal their position as well as to have available a minimum supply of water, food, and medicines.

This is the purpose of the portable emergency [survival] kit.

Depending on the geographic region of aircraft operation, its routes, and its operating range, the content of the portable emergency survival kit may vary. Signaling facilities are of decisive importance in ensuring success of the search operations, since it is extremely difficult to detect a man in a forest, in the ocean, or in a desert from an aircraft or some other form of transportation.

The food included in the survival kit is chosen so as not to induce thirst. In this connection, enriched hard candy is better than chocolate. "Pemmican" (prepared by North American Indians from dried ground meat, grease, and berry juice) is a valuable high-calorie preserved product. It is expedient to package the daily rations individu-

311

ally.

Below we present an approximate enumeration of the items and equipment included in a survival kit, this information having been taken from various foreign sources.

1. An inflatable single-seat rubber raft with a device for rapid inflation.

2. Signaling and detection facilities:

1) a radio transmitter and a direction finder with a power source;

2) a mirror reflector (a heliograph);

3) a pocket flashlight;

4) a smoke signal;

5) signal (firing) cartridges (flares);

6) chemical (luminous materials) to dye the surface of water or snow;

7) a whistle (to signal at sea during fog or in a forest).

3. Nourishment (water and food):

1) flasks with water (replaced with a chemical purifier at sea);

2) cans of meat, cheese, and berries;

3) sugar, hard candy, chocolate;

4) biscuits.

4. Medicines:

1) bandages (gauze and rubber);

2) antiseptics (iodine);

3) burn ointments and pain killers, synthomycine (to prevent stomach upset) in tablet form;

4) injection tubes for subcutaneous injections;

5) pantocide in tablet form to disinfect water taken in lakes and swamps.

5. Survival items:

1) matches in watertight container (windproof or glowing);

2) a compact stove and solid chemical fuel (alcohol or gasoline in briquettes);

3) fishing tackle;

4) a knife-file combination or a folding military dagger;

5) sea-water distiller;

6) a compass;

7) a magnifying lens for ignition;

8) a waterproof poncho;

9) needle and thread.

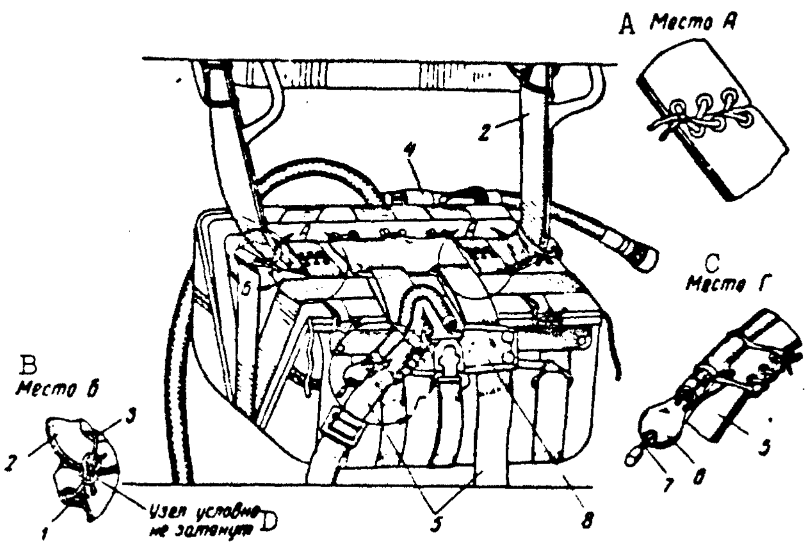


Fig. 213. Attachment of portable emergency survival kit on suspension system of parachute. 1) Backpack straps; 2) main strap of suspension system; 3) lacing; 4) parachute oxygen equipment; 5) leg straps of suspension system; 6) ripcord handle; 7) ripcord; 8) protective covering case for release. A) Position A; B) position B; C) position D; D)

In the case of flights over deserts the raft and distillation unit is replaced by a larger supply of bottled water in quantities up to 6 liters (based on a calculation of 3 liters per day). For flights in the Arctic and during the winter over dry land provision is made for folding-type skis.

All component parts of the survival kit are packed into a single

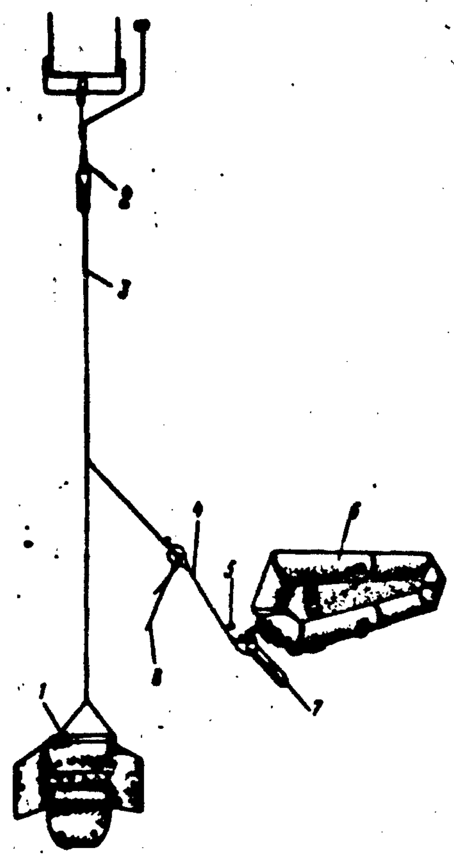


Fig. 214. Diagram of raft release from backpack of portable emergency survival kit and its gas inflation in the air. 1) Portable emergency survival kit; 2) parachute suspension system; 3) shroud line; 4) release line; 5) safety valve; 6) raft; 7) CO_2 bottle; 8) release cable.

backpack which is attached to the suspension system of the parachute. The backpack is stored in the seat bucket or suspended from the pilot's back (Fig. 199 shows a pilot wearing a portable emergency survival kit and a parachute backpack).

The emergency survival kit is packed in a waterproof container and the kit can float. The individual parts of the kit are also made to float or they are connected by means of thin cables to the nonsinking backpack frame made of light plastic foam.

The over-all weight of the portable emergency survival kit intended for deserts or oceans may reach 16 kg. As a rule such a kit is carried in the seat. The backpack is lower in weight and has a limited supply of materials (but not at the expense of signaling facilities).

In order to fasten the NAZ [emergency survival kit] to the suspension system of the parachute, provision is made for a special pack of strong fabric.

Since the NAZ [emergency survival kit] is rather heavy, it is released from its pack prior to landing in water or on the ground and it is lowered on a shroud line (approximately 12-15 m long). For this purpose there is a handle connected by means of a cable to the pack release straps. The cable passes through a flexible tube fastened to the suspension system (Fig. 213). Before landing, a pilot pulls this handle at a height of about 100-200 m, the straps open, and the NAZ [emergency survival kit] falls out from the pack.

The rubber rescue raft is folded so that it is the first to be released from the backpack. The raft is held by the outside flaps of the backpack, which are held shut by means of pegs and slats with the two pins of the release cable.

The gas inflation of the raft is achieved from a carbon-dioxide bottle manually after landing in water (by pulling on the release cable) or automatically as the NAZ [emergency survival kit] is released from the pack on the suspension system. In the latter case, a special short shroud line from the backpack is first (during the preparation for the flight) connected to the release cable of the backpack and with the release line attached to the safety valve of the carbon-dioxide bottle and to the lever which opens the valve of the latter (Fig. 214).

On ejection of the NAZ [emergency survival kit] all shroud lines are tensed and the pins and safety valves are released thus automatically freeing the raft and filling it in the air, before it reaches the water surface.

For landings on dry ground the backpack is provided with shoulder straps to carry the NAZ [kit]. During storage these straps are stuffed into the pocket at the top of the backpack.

The simplest signaling devices (a flashlight, flares) are best stored in an airtight container in special pockets directly on the individual, these pockets sewn into the water survival suit or space pressure suit precisely for this purpose.

The problem of behavior and crew action to ensure survival in the event of the emergency abandonment of an aircraft in desert regions is considered in detail in special literature.*

§11. RELEASE OF "PLUMBING" ON EJECTION

With increasing altitude and flight velocity for aircraft and as the high-altitude equipment becomes more complex the number of required connections has undergone considerable increase (hoses and electric wiring) to connect the pilot with the instruments and assemblies installed in an aircraft cabin.

If a pilot was formerly connected to on-board aircraft equipment by means of a single oxygen hose and a single four-cable electric wire for flights to altitudes below 12,000 m, at the present time in order to execute flights with a high-altitude supersonic pursuit aircraft the following gas and electrical connections are required, as shown in Figs. 188-190:

1) hoses for the on-board oxygen unit......... 1-3
2) air lines:
   antigravity suit.......................... 1
   ventilated suit.......................... 1
3) electrical lines:
   communications (telephone and microphone) 4
   glass heating with temperature regulator. 2-4

All in all, there are up to 5 gas and up to 8 electrical connections.

In order to ensure safe ejection the instantaneous separation of all of the above-enumerated connections must be possible with moderate force (no more than 40-50 kg). At the same time, those gas connections through which oxygen from on-board equipment was supplied to the airtight helmet and the tensioning chambers of a G suit or through which the oxygen and air supply passed to a space pressure suit must be sealed off (by the pilot).

If this were not done, the pilot would not be able to develop the necessary pressure at great altitude for the organism and he may suffer fatal consequences.

Fig. 215. Pilot wearing space pressure suit without mask, the hoses of this suit connected to a consolidated release. 1) Consolidated release; 2) hoses; 3) manual switch for parachute oxygen unit.

The closing off of the connections is carried out automatically by means of return-flow valves.

The air hoses of antigravity and ventilated suits on a land aircraft need not be equipped with return-flow valves. However, if the equipment is used in combination with water survival suits for flights over water, it is obvious that the return-flow valves in these connections are necessary to prevent the entry of water.

The fast-release connections used aboard aircraft can be divided into two types:

1) connection sleeves with calibrated force (known simply as "sleeves");

2) mechanical releases which are opened by means of a static line fastened to the aircraft.

Sleeves are used expediently only for those types of equipment whose disruption of airtightness at great altitudes will not lead to loss of pilot consciousness. These include the antigravity and individually ventilated suits (if the latter is used without a high-altitude space pressure suit).

Maximum reliability is required of the oxygen-hose releases. Random movements and pilot gestures in the cabin (for example, as a result of negative acceleration) should not cause the hoses to release or to disrupt airtightness. At the same time, the release must operate simply and rapidly under normal operating conditions such as, for example, when removing the seat.

For convenience in servicing, reducing the time required to prepare for takeoff, and simultaneous release on ejection all connections are passed through a single unit known as the so-called consolidated connection release. This same unit can effect the automatic actuation of the parachute oxygen unit on ejection.

Consolidated releases are made to incorporate various numbers of connections, depending on the type of equipment with which they are being employed. We should distinguish releases intended for upward or downward ejection seats, since the direction of ejection makes it necessary to vary the manner in which the release is connected to the seat and where it is to be positioned.

Figure 215 shows a pilot in a space pressure suit without a mask, equipped with hoses connected to a consolidated release, as he climbs into the cockpit of his aircraft (USAF).

Operating Principle and Design of Consolidated Releases

The release consists of three basic parts (Fig. 216): two sections 1 and 3 with connection tubes and a middle frame 2, these being connected to one another by means of a mechanical locking device which is incorporated in the release unit. The middle portion of the release is permanently attached to the seat. At the instant of ejection the strap attached to the floor or some other element of cabin structure opens the release and the latter separates into three parts. With this, section 3 (which we have agreed to designate as the lower) together with the on-board hoses and leads 4, 5, 6, and 7 connected to it remain in the aircraft; the middle portion of release 2 remains with the seat, while section 1 (the upper), connected by means of hoses and the personal-equipment leads, remains with the pilot.

The excess pressure in the oxygen system of a G suit or in a space pressure suit after ejection is ensured by means of return-flow valves

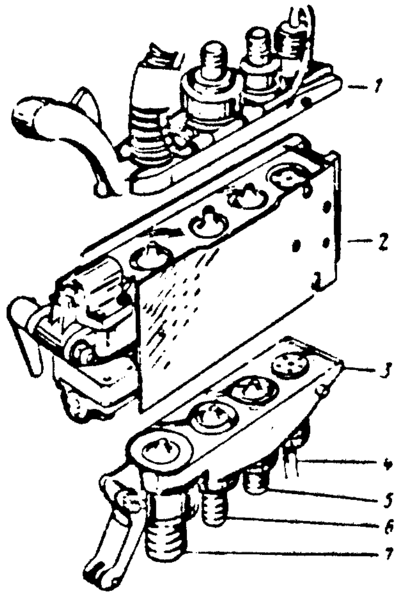


Fig. 216. Three basic elements of a consolidated connection release. 1) Upper section; 2) middle frame; 3) on-board section; 4) communications leads; 5, 6, 7) air and oxygen connections.

installed in the connection tubes of the upper section. Upon release these valves are automatically closed by springs. The return-flow valves of all of the lines (with the exception of the inspiration line) are provided with strong springs and rubber pads. The connection tube of the inspiration-valve line has a mica return-flow valve with an extremely weak spring. If the oxygen reserve from the parachute equipment is consumed during the course of a parachute descent, the pilot can inspire atmospheric air through the mica valve.

The release is made so that it makes it possible to achieve separation not only from the static line, but it also enables the pilot to separate the upper section by himself. This partial separation of the release is employed by the pilot during the course of normal operations so that he can leave the cockpit of the aircraft together with the parachute.

The automatic actuation of the parachute oxygen equipment on ejection is carried out by means of a special hook on the lower section. This hook connects to the eyelet of the release cable for the parachute oxygen equipment immediately upon the initial deflection of the release lever, even prior to the total separation of the upper and lower parts of the release.

In other types of designs in which the pilot, on the ground, does not leave the cockpit with the parachute and oxygen equipment, the cable release is fastened directly to the lower section of the release, e.g., by means of a belaying pin (a bolt with chock and hinge).

Mounting the Consolidated Release on the Seat

Figure 217 shows two of the most common means of setting up consolidated releases on a seat and fastening the static lines for the release as encountered in various foreign publications. The plane pass-

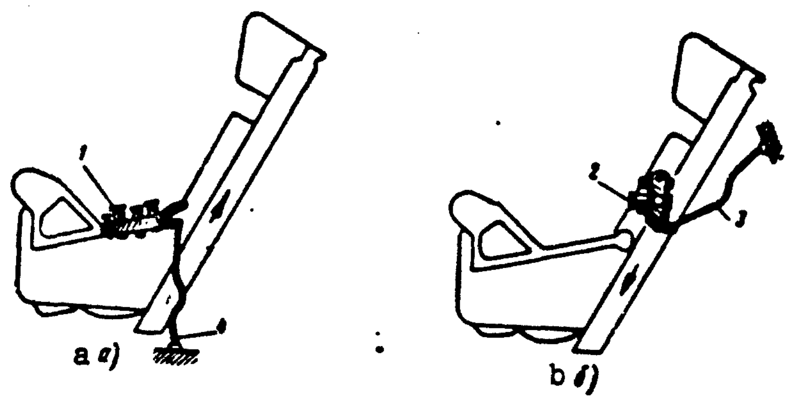


Fig. 217. Versions of consolidated release installation on seat and attachment of static line as function of ejection direction. a) Upward ejection; b) downward ejection. 1) Release for upward ejection; 2) release for downward ejection; 3 and 4) static lines for actuation of release.

ing through the axes of the release connection tubes must be vertical. Until total separation of the release, the release sections should not come into contact with any of the seat elements.

For upward ejection (Fig. 217a) release 1 is mounted on the side surface of the seat bucket, horizontally or at an angle of up to 20° to the side of the release. The static line 4 (cable) for the actuation of the release is positioned vertically or deflected from the vertical by no more than 15°, forward or back, and by no more than 5-7° toward the outside of the cockpit. The deflection of the static line toward the seat is not permitted.

For downward ejection release 2 is mounted vertically, the buckle at the bottom on the side rear support of the seat, to the rear and somewhat above the seat bucket, as shown in Fig. 217b. The static line 3 is fastened to the rear and above the seat. This procedure is employed to prevent the lower section (in the given case, the rear section) of the release from striking the pilot at the instant of ejection and release actuation.

The static force of release actuation may reach 40-50 kg. A fourfold strength margin is required of the static line and its attachment in the cockpit, i.e., these should be designed for a destructive force of the order of 200 kg.

When mounting a consolidated release on a new seat, the entire system must be checked by firing it on a ground catapult, dragging the seat out of the cockpit, and in flight tests with a dummy. When the seat is dragged out of the cockpit, it is important to check to see that the slack of the hoses is greater than the length of the static line.

The slack of the static line is made as small as possible, i.e., it can exceed the range of seat-bucket regulation with respect to height by no more than 20-30 mm.

In order to prevent the upper section of the release from striking the pilot on ejection, it is fastened by means of a strap or rubber bands to the suspension system of the parachute or to the backpack of the latter.

In a number of cases, particularly when the parachute is kept permanently in a container on the back of the seat, the consolidated release is not convenient when the pilot is being seated in the aircraft cockpit. Therefore, additional operational group and individual releases are built in for the connection hoses. In the case of antigravity suits, sleeves are used, while the oxygen hoses are collected into manually operated group releases holding 2-3 hoses each.

The pilot uses these releases during normal operation. In the case of an emergency, however, at the instant of ejection, the consolidated release is actuated to release the pilot from all connections linking him to the aircraft.

§12. COMPARATIVE EVALUATION AND AREA OF APPLICATION FOR VARIOUS FORMS OF HIGH-ALTITUDE EQUIPMENT. CALCULATION OF OXYGEN RESERVE*

Comparative Operational Evaluation of High-Altitude Equipment

An aircraft designer must make proper selection of the high-altitude, survival, and protective equipment complex in accordance with the flight-engineering and operational characteristics of an aircraft. The flight and maintenance crew must have a clear idea as to the operating principle, the potentials, and the limits of application of any given type of equipment or apparatus. A comparison of the basic characteristics of high-altitude equipment (permissible altitudes and flight durations) is presented in Table 23.

These data show the time available to a pilot in the case of cabin depressurization at great altitudes. When using a high-altitude G suit and breathing under excess pressure the pilot has but a few minutes at his disposal and these, however, are sufficient only to descend to a safe altitude of the order of 12,000 m.

The permissible flight time at altitudes of 10-12 km when breathing pure oxygen is a function of the individual properties of the organism and its high-altitude resistance. Each pilot must be aware of his own potentials, these being based on training sessions in a pressure chamber. However, it is recommended that no pilot be called upon to spend more than 30 minutes at an altitude of 12,000 meters. At an altitude of 11,000 meters, and even more so at 10,000 meters, man is capable of functioning normally (when breathing pure oxygen) for many hours, if he experiences no high-altitude pain. For a flight of unlimited duration the altitude should not be higher than 7500 m, and this can be achieved (in addition to the use of a pressurized cabin) only by using a high-altitude pressure suit. In addition to altitude, it is

TABLE 23

Permissible Altitude* and Duration of Flight when Using Oxygen and High-Altitude Equipment

A № по пор.	B Тип снаряжения и аппаратуры	Допустимая C высота *км*	Возможная продолжительность D полета	E Примечание
1	F Кислородный прибор с непрерывной подачей: маска открытого типа	8—10	G До нескольких часов	
	H маска с дополнительной емкостью	11		
2	I Кислородный прибор с периодической подачей (легочный автомат)	12	J До 30 мин.	
		11	Несколько K часов	
3	Кислородный прибор с избы-L точным давлением	14—15	Несколько M минут	
4	Высотный компенсирующий N костюм: маска с избыточным давлением	16—17	O Несколько минут	P Время зависит от высоты полета, качества подгонки костюма, физической нагрузки и индивидуальных особенностей организма
	Q герметический шлем с избыточным давлением	40÷60	От нескольких минут до одного R часа	
5	Высотный скафандр: S „высота" в скафандре 11 *км*	T Не ограничена	U 10—20 час.	V При условии защиты от проникновения озона и температуре 10÷25° C
	W „высота" в скафандре 7,5 *км*	X То же	Не ограни-Y чена	

*The permissible altitude for the application of high-altitude equipment should be determined on the basis of the possible rarefaction in the cabin, and this depends on the shape of the fuselage and canopy and may amount to 35% of the total ram pressure $q_{max\ max}$.

For example, let the rarefaction in the cabin be equal to 25% $q_{max\ max}$, and let the indicated flight velocity V_1 = 1000 km/hr at an altitude of 10,000 meters.

For this case (without correction for compressibility)

$$q_{max\ max} = \frac{0,125}{2}\left(\frac{1000}{3,6}\right)^2 = 4800\ \text{kg/m}^2;$$

the rarefaction in the cabin

$$-\Delta p = \frac{4800 \cdot 25}{100} = 1200\ \text{mm water column (88 mm Hg)}$$

and, consequently, the absolute pressure in the cabin at an altitude of 10,000 meters is (p_{abs} = 198 mm Hg)

$$p_{abs} = 198 - 88 = 110\ \text{mm Hg},$$

which corresponds to an altitude of 13,700 meters; i.e., the "altitude" in the cabin at 3700 m exceeds the flight altitude.

(Continued on next page)

It should be borne in mind that such an elementary calculation method is permissible for comparatively low altitudes, since there is no consideration of a correction factor for the low static pressure.

A) Item No.; B) type of equipment and apparatus; C) permissible altitude, in km; D) potential flight duration; E) note; F) oxygen equipment with continuous feed, open type mask; G) up to several hours; H) mask with additional space; I) oxygen equipment with periodic feed (automatic lung); J) up to 30 minutes; K) several hours; L) oxygen equipment with excess pressure; M) several minutes; N) high-altitude G suit, mask with excess pressure; O) several minutes; P) time is a function of flight altitude, quality of suit fit, physical stress, and individual features of organism; Q) airtight helmet with excess pressure; R) from several minutes to a single hour; S) high-altitude space pressure suit, "altitude" in space pressure suit 11 km; T) unlimited; U) 10-20 hours; V) provided there is protection against penetration of ozone and a temperature of 10-25°C; W) "altitude" in space pressure suit, 7.5 km; X) the same; Y) unlimited.

also necessary to provide man with corresponding temperature conditions within the aircraft cabin or to set up microclimatic conditions by means of ventilated or thermally insulated clothing.

The protective properties of the various pieces of equipment with respect to ram pressure were presented in Table 22. The space pressure suit completely protects man at flight velocities (referred to standard ground conditions) of 1200-1300 km/hr and is superior in this regard to all other forms of individual clothing.

Problems of operational ease are of great significance for the flight crew. It is for this reason that the opinions expressed by pilots operating in various types of flight clothing are of such great interest.

Navy combat pilots have provided the following comparative evaluation of the high-altitude G suit and a space pressure suit, i.e., the high-altitude G suit [VKK] is more comfortable than the space pressure suit when there is no pressure in the tensioning chambers, but on the other hand the space pressure suit is more comfortable and provides greater mobility and vision when inflated. Since accidents involving pressurized cockpits are rare occurrences, many pilots prefer to use

G suits.

From the standpoint of service and operation, an individual VKK [high-altitude G suit] is simpler than a space pressure suit. Only an on-board oxygen system is required for the VKK [high-altitude G suit]. The space pressure suit, in addition to the oxygen supply, requires on-board and ground installations for air conditioning. However, if it becomes necessary to use a VKK in combination with a water survival or ventilated suit, the ground and on-board equipment will be the same as when using a space pressure suit. Therefore, if it is necessary to protect a pilot under conditions both of prolonged high-altitude flight and in the case of an emergency over cold water, the over-all preference will fall to the space pressure suit.

Having compared the various types of space pressure suits, foreign specialists point out that in terms of minimum oxygen flow rate first place is held by the regeneration space pressure suit; after this piece of equipment there follows the ventilated space pressure suit with a mask, and in last position we find the ventilation-type space pressure suit which does not require the use of a mask. With regard to resistance to breathing, the space pressure suit with mask moves to last position, but assumes first rank in terms of minimum carbon-dioxide content in the expired air.

Ventilation space pressure suits for altitudes above 18,000 meters in the opinion of foreign specialists, must be provided with independent inflation above this altitude from a tank, since the entry of ozone into the space pressure suit from the atmospheric air is possible. From the standpoint of protection against ozone and the prevention of high-altitude pains, it is held expedient to supply pure oxygen from the ground up to the helmet of a space pressure suit which uses no mask. In this connection the regeneration space pressure suit exhibits an advantage, and namely, its supply and regeneration system is completely autonomous and insulated from the ambient medium.

From the operational standpoint the ventilated space pressure suits are considered to be simpler than the regeneration suits. For the latter it is necessary to change the regeneration cartridges and, consequently, to provide for regular supplies of appropriate chemicals at airfields.

The space pressure suits which require no masks are given preference for prolonged flights (the mask encloses the face and proves bothersome). Moreover, in these space pressure suits there is no cause to fear vomiting. It is recommended that these suits be used if there is a possibility that the pilot may be turned around during the course of a parachute descent or if he should experience the rocking motion of waves in the case of ditching in water. However, the mask space pressure suit provides for relatively greater safety in case of helmet damage or disruption of its airtightness.

It is thought that space pressure suits, as well as the airtight helmets of high-altitude G suits [VKK] may, with some minor modifications, be used as protection against gas [gasmasks].

Determination of Oxygen Reserve

The over-all weight of the high-altitude equipment depends in great measure on the oxygen flow rate required to supply the members of the crew and this flow rate also governs the oxygen reserve carried aboard the aircraft.

Aboard the aircraft oxygen is stored either in a compressed state in tanks or in liquid form in special containers – gasifiers – representing a type of Dewar jar with additional devices for evaporation of the oxygen and the supply of the oxygen at the required pressure.

There are oxygen tanks with an operating pressure of 150 and 30 atm. Occasionally, spherical oxygen tanks of great capacity with a pressure of 110 atm are used. In the gasifiers the operating oxygen pressure is kept at about 10 kg/cm^2.

The mean relative weight of these oxygen sources (without consideration of the actual weight of the oxygen), referred to a single cubic meter of oxygen under ground conditions, amounts to

for tanks at 150 and 30 atm.............	8.2 kg/m^3
for spherical tanks at 110 atm..........	5 "
for gasifiers...........................	2 "

This average weight increases somewhat for vessels of low capacity and, conversely, diminishes as the capacity of the tanks is increased.

The specific weight of the oxygen (at a pressure of 760 mm Hg and a temperature of 15°C) is equal to 1.354 kg/m^3. One kilogram of liquid oxygen occupies a volume of 0.876 liter and on evaporation yields 736 liters of gas, referred to the indicated ground conditions. In various countries liquid-oxygen gasifiers for 5, 15, and 30 kg are produced.

The oxygen flow rates for various types of oxygen equipment, G suits, and space pressure suits have been indicated above.

Figure 218 shows the oxygen flow rate as a function of flight altitude for the basic types of high-altitude equipment. For units with periodic feed the mean lung ventilation equal to 15 liters per minute has been taken. In the case of space pressure suits it is the general practice to assume that the helmet is sealed airtight from the ground up.

The curves have been constructed for altitudes below 16 km; however, it should be borne in mind that at altitudes above 12 km a constant absolute pressure is maintained in airtight helmets and space pressure suits, and for this reason the oxygen flow rate remains constant. The data in Fig. 218 may be used to determine the required oxy-

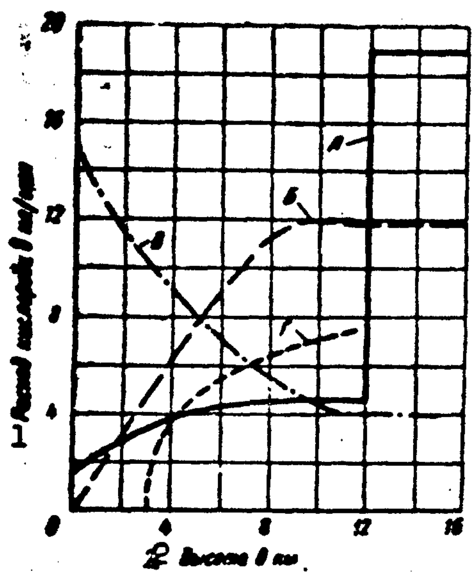


Fig. 218. Oxygen flow rate as a function of "altitude" in cabin when using basic types of high-altitude and oxygen equipment. A) High-altitude G suit; B) ventilation-type space pressure suit without mask; C) ventilation-type space pressure suit with mask (helmet airtight); D) oxygen equipment with continuous feed and mask with additional container. 1) Oxygen flow rate, in standard liters per minute; 2) altitude, in km.
— = A; — = B; — = C; -- = D.

gen reserve.

The oxygen reserve required for a single crew member is a function, in addition to the characteristics of the unit, of the duration and altitude of flight (considering the supply of air in the aircraft, flight duration may be substantial).

The quantity of oxygen G_{potr} required for the flight in the general case consists of the sum of several terms, and namely:

1) G_0 is the oxygen flow rate at the ground during taxiing and anticipation of takeoff (this term is taken into consideration only in the case of fighter aircraft);

2) G_{nab} is the oxygen flow rate during climb;

3) G_{gor}^{gk} is the oxygen flow rate during horizontal flight in pressurized cabin;

4) G_{gor}^{n} is the same, in a depressurized cabin;

5) G_{sp} is the oxygen flow rate during aircraft descent.

The time of flight in a depressurized cabin may vary from 10 minutes for single-seat aircraft to 50% of the total flight duration in the case of multiseat aircraft.

Thus

$$G_{потр}=G_0+G_{наб}+G_{гор}^{гк}+G_{гор}^{н}+G_{сп} \qquad (310)$$

For high-altitude transport aircraft the required quantity of oxygen generally consists of the last two terms (this does not pertain to the determination of the oxygen reserve for pilots, since the pilot controlling the aircraft is compelled for the sake of crew safety continuously to use the oxygen equipment).

The magnitude of each term is computed individually as a function of the duration of a given regime and the oxygen flow-rate norms.

For climbing and descent regimes the oxygen flow rate is defined by the following formulas:

$$\left.\begin{aligned} G_{\text{наб}} &= \frac{q_{H_1} + q_{H_2}}{2}\,\tau_{1-2}, \\ G_{\text{сн}} &= \frac{q_{H_2} + q_{H_1}}{2}\,\tau_{2-1}, \end{aligned}\right\} \qquad (311)$$

where q_{H_1} and q_{H_2} represent the oxygen flow rates, respectively, at altitudes H_1 and H_2, in standard liters per minute (i.e., referred to a pressure of 760 mm Hg and a temperature of +15°C); τ_{1-2} is the time required for the aircraft to climb from an altitude H_1 to the altitude H_2, in minutes; τ_{2-1} is the time required for the aircraft to descend from altitude H_2 to the altitude H_1.

For aircraft with a low rate of climb and limited flight duration a more exact calculation is achieved if the altitude intervals are set at 2000 meters.

It should be borne in mind that when using high-altitude G suits the oxygen flow rate varies significantly between pressurized and depressurized cabins [cockpits] (see Fig. 218). In the event that the airtightness of a cabin is disrupted at great altitudes, the mean oxygen flow rate increases suddenly from 4.5 standard liters per minute to 15-20 standard liters per minute. As the aircraft descends, because of the lag in the diaphragm mechanisms of the oxygen unit, this flow rate may be retained to an altitude of 8 km.

The required water capacity V_b of the tanks is determined from the following expression

$$V_b = \frac{G_{potr}}{p_{b\,max} - p_{b\,min}} p_0 \text{ liters,} \qquad (312)$$

where $p_{b\,max}$ is the maximum oxygen pressure in the tank, in kg/cm^2; $p_{b\,min}$ is the minimum pressure which determines the oxygen reserve in the tank which was not included in the consideration (for the case of a drop in pressure with a change in temperature, to check the unit before takeoff, etc.); $P_0 = 1$ is the pressure at sea level, to which we have referred the oxygen flow rate G_{potr}.

The quantity $p_{b\,min}$ is assumed to be equal to 15-20% of the maximum pressure in the tanks.

When liquid oxygen is used aboard an aircraft, the required capacity of the gasifier is determined from the following formula:

$$G_{gas} = n \frac{G_{potr}}{736} \frac{K}{z} + G_{neuch} + q_{pot} \tau \text{ kg.} \qquad (313)$$

Here 736 refers to the quantity of liters of gaseous oxygen which at a pressure of 760 mm Hg and 15° is produced on the evaporation of 1 kg of liquid oxygen; G_{neuch} is the remainder, not considered, at which the pressure in the gasifier begins to drop. This quantity is taken from the specifications for the gasifier. On the average, it amounts to 7-10% of the liquid-oxygen reserve; q_{pot} is the evaporation loss in kg/hr (these losses for various gasifiers range from 0.05-0.15 kg/hr); τ is the time from the instant of gasifier charging to aircraft takeoff (this time is assumed to range from 24 to 48 hours); K is the safety factor, e.g., in case a portion of the gasifiers break down; n is the number of members in the crew; z is the number of gasifiers.

In the case of multiseat aircraft, the quantity K is assumed to be equal to 2; in the case of single-seat aircraft the gasifiers are not duplicated, since it is felt that an emergency oxygen reserve is available from the parachute oxygen equipment.

Example 1. Determine the required oxygen reserve for a single-seat aircraft for an over-all flight duration of 45 minutes for two types of high-altitude equipment, i.e., a space pressure suit with a mask and a G suit.

The duration of the individual flight regimes is indicated in Table 24.

TABLE 24

Determination of Required Oxygen Reserve for Single-Seat Aircraft

A № по пор.	B Режим полета	C Продолжительность режима мин.	D Расход кислорода			
			E Скафандр		F ВКК	
			G Средний расход нл/мин	Расход за время режима H нл	G Средний расход нл/мин	Расход за время режима H нл
1	Рулежка I	6	15	90	1,6	9,6
2	Набор высоты J	5	10	50	3,5	17,5
3	Горизонтальный полет в загерметизированной кабине ($H_{каб}$ = 8 км) K	20	5,5	110	4,5	90
4	Горизонтальный полет в разгерметизированной кабине на высотах более 12 000 м L	10	4	40	19	190
5	Снижение с потолка до 8000 м M	2	4,75	9,5	19	38
6	Снижение с 8 до 3 км N	1,5	7,5	11,3	3,5	5,3
	O Всего:	45	—	410,8	—	410,4

A) Item No.; B) flight regime; C) duration of regime, in minutes; D) oxygen flow rate; E) space pressure suit; F) VKK [high-altitude G suit]; G) average flow rate, in standard liters per minute; H) flow rate during the regime, in standard liters; I) taxiing; J) climbing; K) horizontal flight in pressurized cabin (H_{kab} = 8 km); L) horizontal flight in depressurized cabin at altitudes in excess of 12,000 m; M) descent from ceiling to 8000 meters; N) descent from 8 to 3 km; O) total.

Solution. The norms for the oxygen flow rate are taken from the curves presented in Fig. 218. The average oxygen flow rate for the climbing and descent regimes are determined on the basis of Formulas (311). The derived results are noted in the corresponding columns of Table 24. Multiplying the average flow rate by the time of the corresponding regime, we obtain the oxygen flow rate during the course of the given flight regime. These results are also recorded in the corresponding columns.

Summing the flow rates, we define the total quantity of oxygen required for the execution of the flight. For our example this quantity proved to be identical for a space pressure suit and a high-altitude G suit, and was equal to ~411 standard liters per minute (at a pressure of 760 mm Hg and t = 15°C).*

The required tank capacity is determined from Formula (312)

$$V_6 = \frac{411}{150 - 30} \approx 3.5 \text{ liters.}$$

Since tanks with a capacity of 3.5 liters (or 1.5 liters) are not being produced, it becomes necessary to take a tank with a capacity of liters having an operating pressure of 150 atm.

Example 2. Determine the required oxygen reserve for a three-seat aircraft and a flight duration of 10 hours for two types of space pressure suits, i.e., ventilation-type space pressure suits with and without masks.

Given: the "altitude" in the pressurized cabin for the horizontal flight regime is equal to 6000 meters. The flight time in the depressurized cabin may amount to 50% of the total flight duration. The oxygen reserve is taken in liquid form in the gasifiers.

Solution. The oxygen flow-rate norms are taken from the curves in Fig. 218. For a multiseat aircraft we can limit ourselves to the basic theoretical case, i.e., the horizontal flight regime.

For a space pressure suit with a mask the theoretical case corresponds to a flight in a pressurized cabin (7 standard liters per minute at an altitude of 6000 meters):

$$G_{\text{herp}} = 7 \cdot 60 \cdot 10 = 4200 \text{ liters per 1 man.}$$

For the case of a space pressure suit without a mask in which the oxygen flow rate increases with increasing flight altitude G_{potr} is defined as the sum of the oxygen flow rates during flight in a pressurized (9 standard liters per minute) and a depressurized cabin (12 standard liters per minute):

$$G_{\text{потр}} = 9\cdot 60\cdot 5 + 12\cdot 60\cdot 5 = 6300 \text{ liters per 1 man.}$$

The required liquid-oxygen gasifier capacity is defined according to Formula (313) for $G_{potr} = 6300$ standard liters per minute. Let us assume that the losses in a gasifier due to spontaneous evaporation amount to 0.08 kg/hr; the charging of the tanks is carried out 48 hours prior to takeoff; the liquid-oxygen remainder that has not been taken into consideration is equal to 1.5 kg and the containers are duplicated (the coefficient $K = 2$). The required capacity of a single gasifier for a total number of gasifiers $z = 2$:

$$G_{\text{газ}} = \frac{3\cdot 6300\cdot 2}{736\cdot 2} + 1{,}5 + 0{,}08\cdot 48 = 31 \text{ kg.}$$

When the number of gasifiers is increased to 4, the required capacity of a single gasifier amounts to 18.7 kg of liquid oxygen.

Manuscript Page No.	[Footnotes]
29	Compiled on the basis of the following materials: G. Armstrong, Aviatsionnaya meditsina, IL [Aviation Medicine, Foreign Literature Press], 1947. Geratevol', Psikhologiya cheloveka v polete [The Psychology of Man in Flight], IL, 1956. Fiziologiya i gigiyena vysotnogo poleta, Biomedgiz [The Physiology and Hygiene of High-Altitude Flight, Biomedical Press], 1938. Voprosy aviatsionnoy meditsiny [Problems of Aviation Medicine], IL, 1954.
33	In the specialized literature this form of anoxia [oxygen starvation] is known as hypoxia.
34	The reserve time is determined experimentally, i.e., from the instant at which the oxygen supply is cut off (or from the instant of a rapid ascent to a given altitude) to the initial manifestation of an inability to function properly, this being expressed by distortion of handwriting.
36	The term decompression tissue emphysema is also used.
40	After the data of Regener — S.K. Mitra, Verkhnyaya atmosfera [The Upper Atmosphere], IL, 1955. The thickness of the ozone layer, at this altitude contained in an air layer 1 km thick, has been referred to normal conditions.
53	A.H. Schwichtenberg, Is it Working? Flying Safety, Vol. 11, 1955, No. 3, pages 12-13.
58	Flying, Vol. 61, 1957, No. 1, pages 31, 84-89.
74	On the basis of information in the "Aviation Week" issue of 24 December 1955, the record ascent in a pressure chamber to an altitude of 60,000 m by Major A. Bek of the Aerospace Medical Laboratory was carried out in the USA, the Major wearing an MS-4 G-suit. The limiting flight altitude in a G suit depends on a variety of factors including flight duration, the operational refinement of the suit, the physical and emotional state of the pilot, the amount of rest and the level of food intake prior to the ascent, etc.
82	Aviation Magazine, 1 February 1960, No. 292. Flight 1956, June 22. Flight 1957, September 6. Flying Safety, March 1957.
90	Interavia, Vol. 12, 1957, No. 7, page 688.
93*	Aviation Medicine, Vol. 30, April 1959, No. 4. Naval Aviation News, August 1958. Aviation Week, June 22, 1959.

Manu-script Page No.	[Footnotes (Continued)]
93**	"Aviation Medicine," Vol. 30, 1959, No. 4.
94	See the first footnote on page 93 and [29], [30].
95	In a number of cases (for example, in the American X-15 aircraft) body ventilation is carried out with nitrogen which is available on-board the aircraft in liquid form and is used to cool the electronic equipment, the nose portion of the fuselage, etc.
101*	Missiles and Rockets, November 16, 1959. Proceedings of the American Astronautical Society, 1958.
101**	Aviation Week, June 22, 1959. Missiles and Rockets, November 16, 1959.
106	Development History of the Aviator's Full Pressure Suit in the U.S. Navy, "Aviation Medicine," Vol. 30, 1959, No. 4.
109	Naval Aviation News, August, 1958.
110	For the derivation of Formula (307) see L.T. Bykov, M.S. Yegorov, P.V. Tarasov, Vysotnoye oborudovaniye samoletov, Oborongiz [High-Altitude Aircraft Equipment, State Defense Industry Press], 1958.
114*	A. Barton and O. Edkholm, Chelovek v usloviyakh kholoda [Man under Conditions of Cold], IL, 1957.
114**	N.K. Vitte, Teplovoy obmen cheloveka i yego gigiyenicheskoye znacheniye. Medgiz USSR [Heat Transfer in Man and its Hygienic Significance. Medical Press of the UkrSSR], Kiev, 1956.
120	USA Full Pressure Space Suit is Light; Permits Free Movement, Aviation Week, Vol. 67, 1957, No. 23, page 29, Ill. 1.
121	"Aviation Medicine," Vol. 26, 1955, No. 1, page 5660.
125	Naval Aviation News, March, 1960. Aerospace Medicine, April, 1960.
130	Aboard American aircraft carriers the pilot ready rooms are equipped with similar devices.
132*	In addition it should be pointed out that on 19-20 August 1957, in the USA, David Simons [sic], a major in the Medical Corp., completed a 32-hour flight in an airtight gondola of a balloon to an altitude of 21-30 km. No information as to harmful biological effects of radiation has been published.
132**	T. Charles Helvey, Radiation Protective Suiting, Air Force, Vol. 41, 1958, No. 12.

Manu-
script
Page
No.

[Footnotes (Continued)]

136 See the footnote on page 120.

141 "Voprosy aviatsionnoy meditsiny," Collection of translations, IL, 1954.

150 N.K. Pyneyev, Deystviya ekipazha samoleta, vynuzhdenno popavshego v bezlyudnuyu mestnost', Voyenizdat [Actions of Aircraft Crew Forced to Abandon Their Aircraft in an Uninhabited Area, Military Press], 1957.

156 Naval Aviation News, 1958, August.

166 If the space pressure suit is not sealed airtight at the ground but, for example, at an altitude of 4 km, the required oxygen reserve for the space pressure suit would be smaller by a factor of 25% than in the case of a G suit.

Manu-script Page No.	[Transliterated Symbols]
42	к = k = kabina = cockpit
50	в = v = vozdukh = air
50	л = l = legochnaya [ventilyatsiya] = lung [ventilation]
65	ПКП = PKP = parashyutnyye kislorodnyye pribory = parachute oxygen equipment
73	ВКК = VKK = vysotnyye kompensiruyushchiye kostyumy = high-altitude G suits
76	к = k = kamera = chamber
110	в = v = ventilyatsiya = ventilation
110	доп = dop = dopustimoye = permissible
110	п = p = podavayemyy [gaz] = supplied [gas]
110	и = i = [original not identified] = human exhalation of carbon dioxide
111	а = a = absolyutnaya = absolute
157	каб = kab = kabina = cockpit
162	потр = potr = potrebnoye = required
162	наб = nab = nabor = climb
162	гор = gor = gorizontal'nyy = horizontal
162	гк = gk = germetizirovannaya kabina = pressurized cabin
162	н = n = normal'noye = normal
162	сп = sp = spusk = descent
163	б = b = ballon = tank
164	газ = gaz = gaz = gas
164	неуч = neuch = neuchityvayemyy = not considered
164	пот = pot = poteri = losses

Chapter 10

TESTING OF SURVIVAL AND RESCUE EQUIPMENT*

§1. GENERAL REMARKS

The determining and most convincing type of integrated test of rescue and survival facilities is the flight test. It is only in actual flight that it becomes possible to reproduce completely all conditions of emergency evacuation of an aircraft. However, flight tests are relatively expensive measures, particularly if we take into consideration the expenses associated with the construction of flying testbeds.

Seats in multiseat aircraft can to some extent be tested in the actual aircraft for which they are intended, or in some similar aircraft. The testing of seats for single-seat aircraft calls for the construction of a special aircraft, i.e., a "flying laboratory."

To ensure the operational reliability of rescue equipment, as well as to provide for the safety of the flight personnel in a "flying laboratory" it is necessary for a thorough study of the test subject to be undertaken prior to the flight test. Therefore, before a seat is turned over for flight tests it must be subjected to a large and complex series of ground studies. The general sequence of these tests is the following:

1. <u>"Functional" tests.</u> It is the purpose of these tests to check the functioning of all assemblies or, in other words, to check the operation of all seat units and of the high-altitude equipment which must be operational in an aircraft cabin [cockpit] during flight and

in the event of an emergency to the instant of firing-mechanism actuation. Similar tests are carried out under conventional conditions, and in the presence of vibration and a range of temperatures and pressures corresponding to the operating conditions for the seat.

2. Strength tests. Static tests in no way differ from static tests for any assembly, but in the case of a seat and high-altitude equipment there is also the action of dynamic load (with the extension of stabilizing panels and parachutes, on firing of cannons, the ejection of parachutes, upon entry of the seat into the airstream, etc.). To reproduce these stresses in the laboratory, special installations are required.

3. Checking of seat efficiency during the process of seat ejection from the cabin [cockpit]. These tests are conducted on the so-called vertical catapult (see Fig. 11 and Fig. 225). The vertical catapult is a slightly inclined girder 25 and more meters long along which guide rails have been laid down; these guide rails are a continuation of the rails found in the cabin [cockpit]. After the actuation of the firing mechanism the seat slides along these guide rails, and the braking is achieved through the force of gravity and by means of a special braking mechanism. On this catapult it is possible to reproduce all processes taking place prior to the instant that the seat enters the airstream.

4. Checking the effect of the airstream. The purpose of these tests is to check the efficiency of all assemblies protecting the individual against ram pressure (protective clothing, arm and leg restrainers, rigid protection, etc.). Simultaneously with these tests, the strength of the seat is also tested (in first place, the strength of the minor units for which it is impossible to calculate the stresses to which they are subjected), and the operation of the releases under

conditions of aerodynamic load. These tests are carried out in wind tunnels. If these tests are carried out in tunnels with a closed test section, a fast-acting valve is installed in front of the seat to simulate the aerodynamic shock which is experienced as the seat enters the airstream. During the conduct of such tests in wind tunnels with an open test section, the seat is inserted into the airstream by means of a special mechanism.

5. Checking the effect of deceleration drag on a seat. The purpose of these tests is primarily to determine the ability of a man to withstand inertial stresses in the seat being tested, i.e., to determine the strength and comfort of the harness system. Simultaneously, the strength of the seat is tested for this type of stress and for the absence of false actuation of the releases and control mechanisms as a result of inertial forces. These tests are carried out on a rocket sled to which the required acceleration is imparted by means of a reaction-thrust booster, a pyromechanism, or by means of some pneumatic device.

6. Tests on high-speed reaction-thrust sleds. The purpose of this test is to determine the concurrent effect of ram pressure and deceleration drag on the seat. The sleds set into motion by means of a reaction-thrust booster move on runners along guide rails, attaining velocities of up to 2000 km/hr. Tests with such sleds make it possible more exactly to reproduce flight conditions. When the guide rails are positioned along a deep cliff it becomes possible on ejection from such a sled to test a parachute system as well. If, however, no cliff is available, only the first segment of the seat trajectory after ejection can be reproduced.*

At all stages, tests are initially conducted with a dummy, and then with human beings. Only after the completion of all these tests is the ejection installation passed on for flight tests.

It should be borne in mind that the ground tests are carried out not only to facilitate and reduce the length of time required for the flight tests, but also in order to determine strength safety margins and the limits of seat application. The cited stands may be used to determine the operation of the seat for accelerations and ram pressures virtually inaccessible under flight test conditions.

The above-enumerated types of tests naturally do not exhaust all of the work which must be carried out in the finishing stages of a seat and in the research being done in this area.

When ejection through the canopy is the theoretical case or the design of the firing-mechanism attachment leaves room for doubt, the seat is fired from the aircraft cabin [cockpit] at the ground. Special nets are required in this case to prevent damage to the seat through impact with the ground.

To test the effect of accelerations, particularly those of prolonged action, tests are conducted on large centrifuges.

The operation of parachute systems on descent from great altitudes is tested by ejecting seats from balloons or rockets, similar to the familiar method of tests involving the sending of dogs aloft in rockets.

The wide use of high-speed motion-picture photography is an outstanding feature of the measurements carried out during the course of these tests. The brief duration of the processes taking place during the course of the tests and the presence of a man or dummy whose position cannot be defined by a single or several coordinates make high-speed motion-picture photography the most important tool of the tests. Generally no less than 2 or 3 cameras are set up, and the rate of frame exposure is no less than 100 frames per second.

In addition to the motion-picture photography method, measurements are carried out with conventional instruments, i.e., automatic recording units or oscillographs. The extraordinary brief duration of the majority of processes demands the use of electronic (high-frequency) apparatus.

§2. JET-PROPELLED SLEDS AND TESTS CARRIED OUT WITH THESE

Figure 219 shows a schematic diagram of such an installation. A sled set into motion by one or several jet engines moves along a track sometimes as much as 10 km long on runners. In order to avoid the sled leaving the tracks, the runners are generally fastened to enclose the rails on three sides.

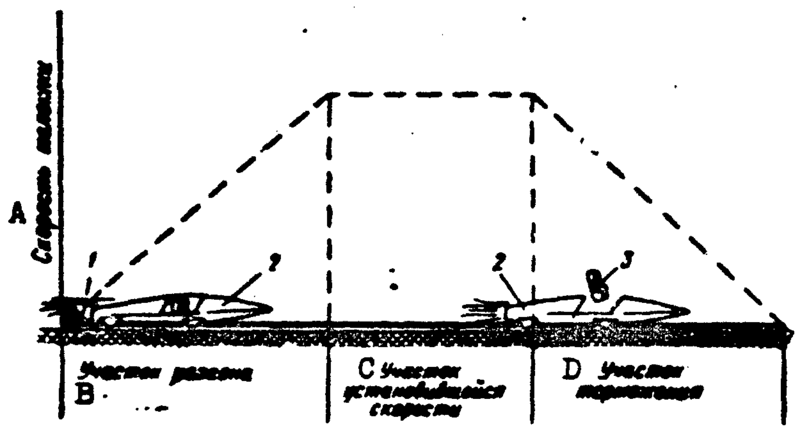


Fig. 219. Schematic diagram of reaction-thrust guide-rail installation. 1) Track; 2) rocket sled; 3) seat being tested. A) [Rocket] sled velocity; B) acceleration section; C) steady-state velocity section; D) deceleration section.

Let us consider the length of track that is required in this case and let us also examine the nature of the tests which can be performed with such a sled. If the tests involve a human being, the horizontal acceleration of the sled is limited and should not exceed a factor of approximately 10.

The velocity of the sled at the end of the acceleration section is expressed by the following formula

$$V = \sqrt{2gns}.$$

Consequently, in order to attain a velocity of 500 m/sec for n = 10 the track must be 1.25 km long.

Since the average deceleration drag should also not exceed 10, the deceleration section should be of equal length, i.e., 1.25 km.

If it is held that a constant-velocity interval must be maintained for a period of 1 second, the total length proves to be equal to 3 km. In other words, over a relatively small path of 3 km, developing accelerations that can be tolerated by a human being, we will obtain an indicated speed of 1800 km/hr, a ram pressure of 15,500 kg/m^2, and a Mach number of about 1.5. An increase in track length or in permissible acceleration (for tests with a dummy) can be achieved with such a sled, and it is also possible to obtain considerably greater velocities.

Generally such sleds are designed for a variety of purposes, i.e., they are employed for tests of a great variety of subjects. We will dwell only on those tests that are directly associated with ejection seats.

Investigation of Simultaneous Effect of Acceleration Drag and Ram Pressure

For the purposes of these tests the seat (with the test subject seated on the sled) is injected into the airstream at the beginning of the deceleration section. The injection into the airstream is most frequently achieved by removal or jettisoning of the protective panel. The most correct approach is the one in which the seat is injected into the airstream by means of a special device, since in this case the influence of fuselage and subsequent exposure of various parts of the pilot's body is also simulated. Simultaneously with the onset of exposure to the airstream the rocket sled is subjected to brief intense deceleration in order to set up deceleration drag. This deceleration must produce G forces which vary according to a predetermined law from he maximum (of the order of 30-35) to 10, as required to bring the sled to a stop on the given track.

These tests simulate the ejection of the seat from the cabin cockpit] into the airstream. If the seat ejected into the airstream can turn about the axis passing through its center of gravity, it becomes possible to simulate the rotation of the seat upon entry into the airstream and, consequently, to check the deceleration drag, angular velocity, and angular acceleration that can be withstood by a pilot. In this case, virtually all parameters of seat motion with the exception of trajectory and parachute descent are simulated.

To reproduce the trajectory the seat must be ejected (in this case with a mannequin). During these tests the problem of recovering the seat and the mannequin is one of extreme importance. This problem can be resolved in a variety of ways.

Occasionally safety nets are set up along the track and the seat is ejected at a small angle. Apparently, the best version is the laying of the track so that it runs off a cliff (Fig. 220) with the seat flying over the cliff due to inertia after ejection, recovery being insured by a parachute system. In this case, the sled must be decelerated prior to reaching the cliff or it must fly off over the cliff and make use of its own parachute system. These tests make it possible to reproduce the entire ejection process, i.e., the trajectory and rotation of the seat about its center of gravity and the operation of the parachute system. It is of course true that these tests represent the identical effect of actual conditions only for low flight altitudes, but nevertheless their results yield virtually inexhaustible material.

In addition to the primary tests, a sled of this type may be employed to carry out a variety of auxiliary tests such as, for example,

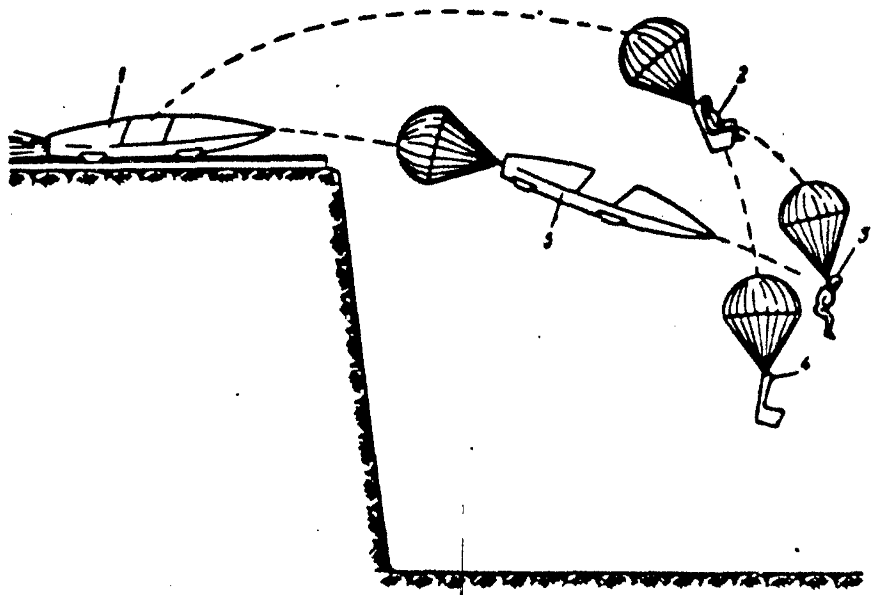


Fig. 220. Diagram showing rescue of test subject on installation positioned at the edge of a cliff. 1) Rocket sled; 2) seat with mannequin; 3) rescue of mannequin; 4) rescue of seat; 5) rescue of sled.

parachute tests, tests to determine the effect of acceleration alone, or to determine only the effect of ram pressure, etc.

It is felt that such a jet-propelled guide-rail installation provides the best reproduction [simulation] under ground conditions of all of the phenomena occurring during the emergency evacuation of an aircraft.

However, rocket sleds, as noted in the foreign press, exhibit a number of shortcomings. One of these shortcomings is the complexity involved in regulating velocity. With existing jet engines the thrust and, consequently, the steady-state velocity of a sled may be maintained within a limited range. If it becomes necessary for some reason or other to obtain data at constant velocity (zero acceleration), it becomes necessary to introduce correction factors for the readings of the accelerometer.

Another shortcoming of the guide-rail installation is the fact that the model on the jet-propelled installation experiences vibrations.

Rocket sled tests have found widespread application in recent times. In the United States for example there are at the present time five large reaction-thrust installations and a number of small units. The large tracks include:

1) the SNORT at China Lake, 6500 meters long (Fig. 221);

2) Boker China Lake, track 4200 meters long;

3) Edwards Air Force Base, track 6000 meters long;

4) Holloman Air Force Base, track being extended to 10,600 meters (Fig. 222);

5) SMART, Hurricane Mesa (in Utah), track 3600 meters.

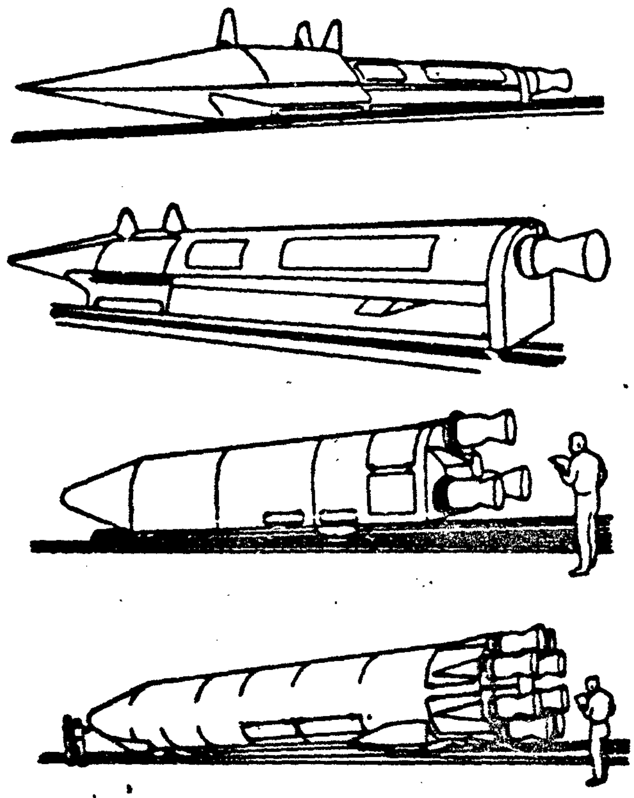


Fig. 221. Rocket sleds used at the SNORT installation.

The greatest velocity obtained in America during such tests was of the order of 3500 km/hr at the SNORT track with a monorail sled. A run over this same track with a double-rail sled resulted in a velocity of the order of 2740 km/hr.

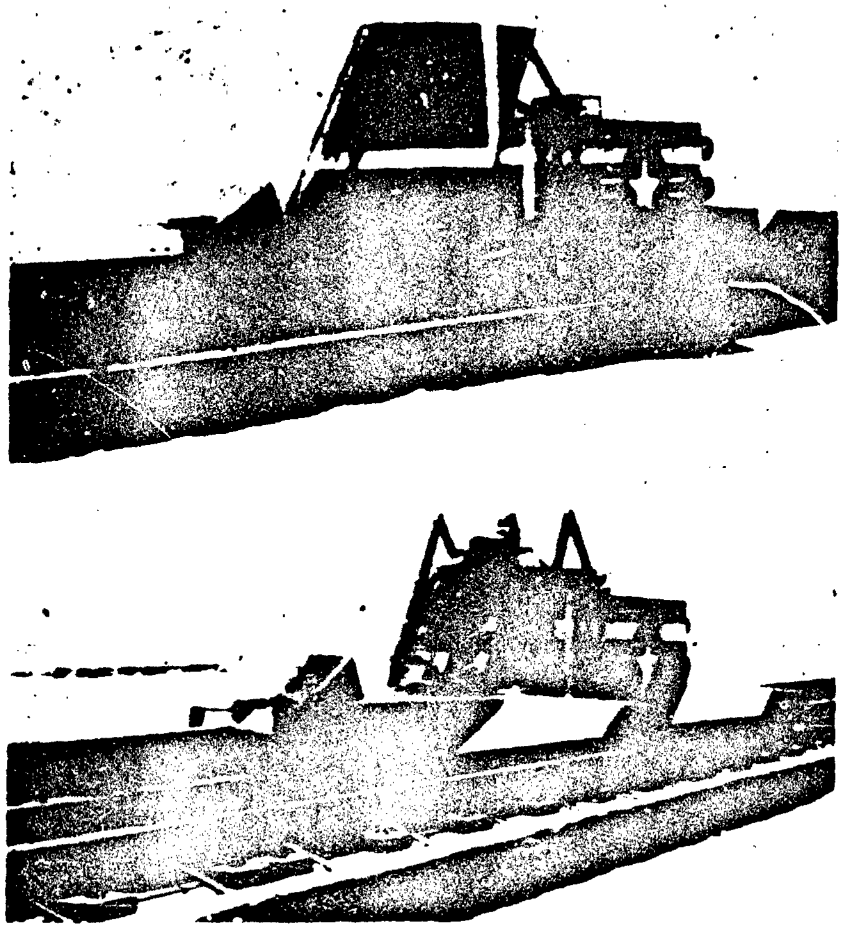


Fig. 222. Rocket sled used at the Holloman AFB installation.

An outstanding feature of the Holloman track is a ravine some 460 meters deep. Parachute systems can be tested on this track as well as virtually all conditions encountered during the course of the ejection procedure.

Rocket-Sled Braking System

At the present time, for large installations, a hydraulic braking system is the one most frequently employed. This system consists of a scoop brake mounted in the lower portion of the sled which is immersed into a trough with water between the rails. The scoop is immersed in the water because the rails themselves are lowered in the braking section in order gradually to lower the rocket sled to the water. The slope is equal to approximately 150 mm over a 600-meter section of track. As the scoop is immersed it gathers up water and ejects streams of water (Fig. 223). This produces a tremendous decelerating force. This braking system, despite its obvious simplicity, naturally cannot be used at negative temperatures without replacing the water with some nonfreezing solution.

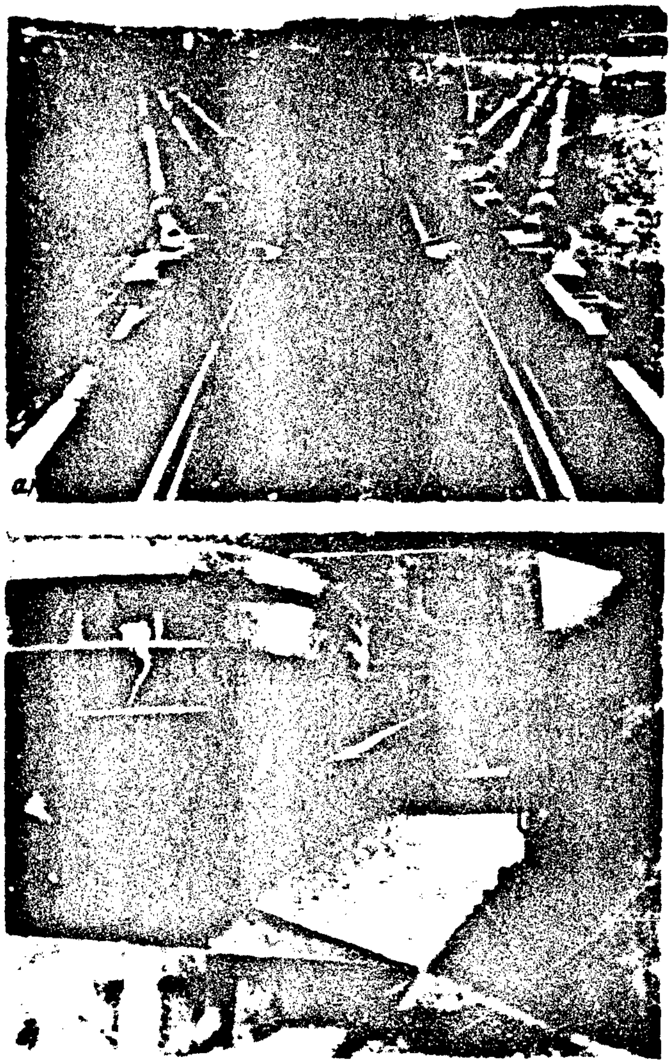


Fig. 223. Braking device. a) Water brake, its third rail and concrete support; b) water-brake scoop.

§3. EJECTION-SEAT TESTS IN WIND TUNNELS

In certain respects wind-tunnel tests are regarded more convenient than with rocket sleds. This pertains to tests of assemblies for which

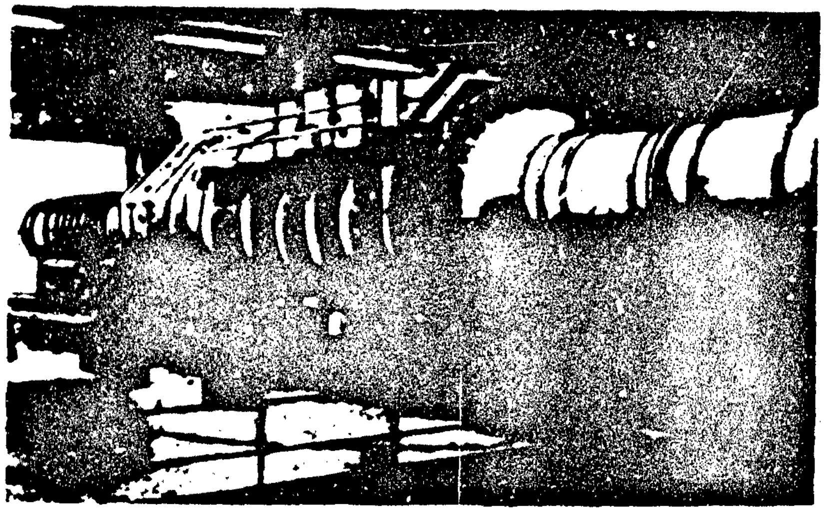


Fig. 224. Over-all view of wind tunnel at the Arnold Engineering Development Center.

airstream pressure is of primary importance, the forces of inertia being negligible. These assemblies include primarily all those designed to protect against ram pressure, i.e., protective and high-altitude clothing, arm restraints, and to a lesser degree, leg restraints. The actual wind-tunnel measurements are simpler, more conventional and, what is most important, thoroughly tested apparatus is available for purposes of these measurements. In other words, wind-tunnel tests are not carried out because rocket-sled tests are expensive and complex but are rather a necessary stage in the development of an ejection seat. As has already been stated, such tests are carried out in wind tunnels with both open and closed test sections. As an example let us describe in detail one such installation with a closed test section.

This installation was developed at the Arnold Engineering Development Center (USA, Tullahoma, Tennessee). An over-all view of this wind tunnel is shown in Fig. 224.

The ram pressure in this wind tunnel ranges from 1200 to 10,000 kg/m^2; the test chamber has a diameter of 3.6 meters and it is 10.6 meters long. For purposes of these tests the following were especially fabricated:

1. A funnel having dimensions of 0.6 × 1.2 meters.

2. A device to mount the ejection seat in such a manner as to permit positioning the seat in positions corresponding to ejection:

a) at a forward angle of 27° and 45° with respect to the ejection position;

b) at a backward angle of 45° and 65° with respect to the ejection position.

3. A fast-acting valve.

This installation was used to carry out tests of the flailing of arms and legs for purposes of obtaining comparative results in terms of similar tests carried out with a rocket sled.

These tests demonstrated the possibility of using wind tunnels for the solution of such problems.

It is maintained that the exact ram-pressure value at which disruption of any given component part takes place can be determined if the instant of destruction and the curve of increasing ram pressure with time are known. These data are more difficult to obtain with rocket sleds than in wind tunnels.

§4. TESTS ON EJECTION INSTALLATIONS AND CENTRIFUGES

If the tests of the influence exerted by ram pressure on abandonment of an aircraft are assumed to be more conveniently studied with the above-described rocket sleds and in wind tunnels, in the case of physiological investigations, in addition to the installations described above, use is also made of vertical and horizontal catapulting devices and special centrifuges.

In order to have some idea as to the appearance of a contemporary laboratory for the study of survival facilities, let us present a brief description of the equipment at the scientific-experimental station of the United States Navy.

Physiological Testing Laboratory

It is the function of this laboratory to carry out general physiological research associated with the conditions of survival and emergency abandonment of aircraft.

The special testing equipment at the laboratory includes:

1. A large heat and pressure chamber.

2. A ground catapult, 33.5 meters high.

3. Special nets used in the case of free ejection from the ground.

4. An impulse, pneumatic, horizontal sled to test the stresses developed by deceleration drag.

5. A large centrifuge.

Let us describe each of the installations separately.

The Ground Catapult, 33.5 meters High

This catapult (Fig. 225) was built in Great Britain by the Martin-Beyker Company for the USN. It is set up on a platform equipped with a special net. Its height (33.5 m) makes it possible to test objects weighing up to 250 kg at a positive acceleration of up to 23g.

Flight crews are trained on this catapult and the ability of man to withstand the accelerations developed under specific conditions are studied here (for a given ejection-seat design and given high-altitude equipment). Moreover, by means of this catapult it is possible to evaluate new ejection-seat configurations and various combinations of seats involving a firing mechanism.

The measuring equipment on the vertical catapult makes it possible to establish the acceleration with high accuracy both over the entire trajectory of the ejection seat and with respect to time, counting from the instant of ejection.

Motion-picture photography with a high frame speed permits determination of position and condition of test subject with respect to time.

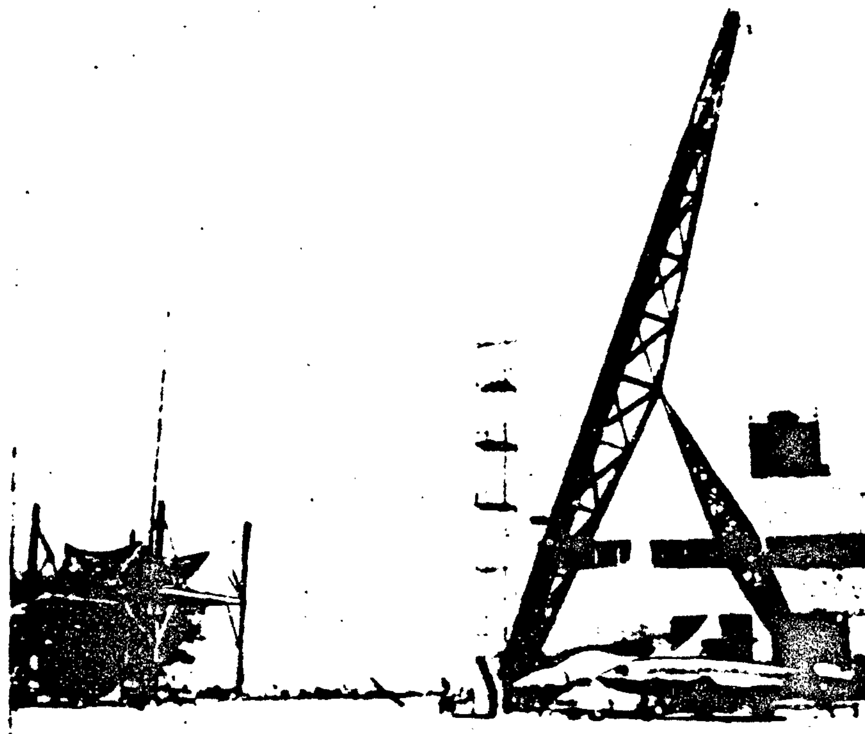


Fig. 225. Vertical catapult and safety net, USN.

The installation is provided with strain-gauge measuring equipment that permits determination of the magnitude and time of stress development at any given point in the structure.

The safety net is employed for free ejection from a small ground catapult; this net is one of the largest in the USA and can also be used for aircraft ejection from a standstill. This net ensures safe return to the ground of objects whose weight is in excess of 230 kg with a flight velocity for the object in excess of 25 m/sec.

Horizontal Impulse Sled (Catapult)

The horizontal catapult shown in Fig. 226 has a pneumatic drive and pneumatic control. The piston stroke of the catapult is 2290 mm. The length of the sled track is 70 m. The catapult makes it possible to attain G forces of 40 for a rocket weight of 1360 kg. For purposes of rapid deceleration the catapult is equipped with a pneumatic brake.

Dynamic tests of ejection seats and harness systems both with dummies and live people are carried out on this catapult.

This installation, just as the vertical catapult, is equipped with measuring and motion-picture photography equipment to permit adequate monitoring during the course of the experiment of the condition of the test object.

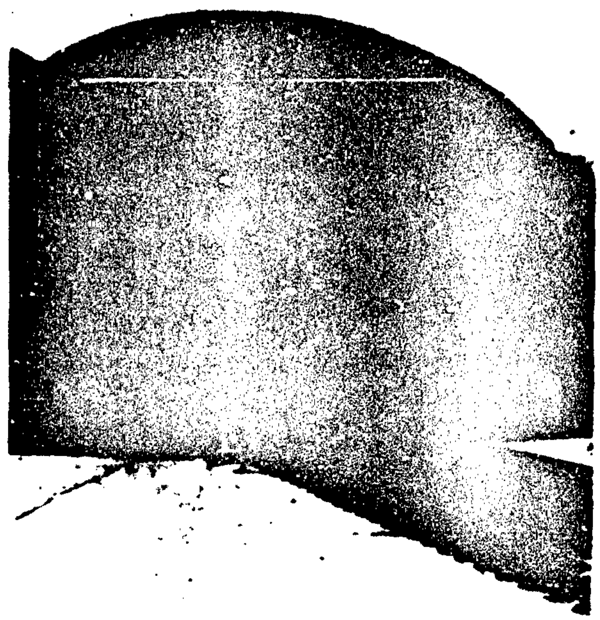


Fig. 226. Horizontal catapult, USN.

The Large Centrifuge for Physiological Investigations

The most interesting installation at this laboratory is the centrifuge (Fig. 227).

The central portion of the centrifuge work area is occupied by an electric motor developing power of 4000 hp, supplied from a DC source. The centrifuge rotor is seated directly on a 15.2-meter beam made of steel tubes. At the end of this beam, a spherical gondola 1.8 × 3.05 m is positioned on two hinged units which can be rotated by individual electric motors as the beam moves.

The control of the hinge-unit electric motors can be programed from the control room built into the ceiling.

Fig. 227. Large centrifuge for physiological research, USN.

The design of the centrifuge permits the execution of complex movements by the gondola with cyclical variations in the angles of pitch and roll according to a preset program. The gondola is designed for stresses of 272 kg. Rarefaction corresponding to an altitude of 18,300 m can be developed in the gondola.

The air conditioning system makes it possible to change the temperature in the gondola from 6.6 to 43°C. The centrifuge can be accelerated to a circumferential gondola velocity of 290 km/hr in less than 7 seconds. The maximum accelerations which can be obtained with a rotating beam and a maximum stress in the gondola of 280 kg ranges from 0 to 1.5g within 0.5 sec; from 1.5 to 15g within 1.35 sec; from 15 to 40g within 5 sec; or from 0 to 40g within 6.85 sec. Using the electric-motor driven hinged units it is possible to obtain accelerations up to 20g and to rotate the gondola at a speed of 30 rpm with linear acceleration within a 20 unit range.

An individual's behavior in executing work is studied by means of television cameras, high-speed motion-picture equipment, high-speed x-ray equipment, and other sensing elements of the physiological functions of the human organism.

An additional two centrifuges of considerably smaller dimensions are employed at this laboratory.

Similar installations to those described above exist at the present time in most countries. They differ as to design and range of application, but in general their operational principles are identical.

§5. HIGH-ALTITUDE EQUIPMENT TESTS IN HEAT AND PRESSURE CHAMBERS

Heat and pressure chambers make it possible simultaneously to check the influence of two primary factors, i.e., low barometric pressure and various ambient-air temperatures. Occasionally heat and pressure chambers are fitted out with devices to produce ozone or to reproduce certain types of radiant energy.

The heat and pressure chamber designed for tests of high-altitude equipment consists of a cylindrical or rectangular housing with a volume from 8 to 50 m^3. The strength of the chamber is calculated for an outside excess pressure of 1 kg/cm^2 (i.e., for a total vacuum inside the chamber). The walls of the chamber are generally welded of steel plate (Fig. 228). The large-volume chambers are occasionally made of reinforced concrete. The entire chamber surface and the surfaces of the refrigeration tubing are covered with a thick layer of thermal insulation. The observation windows have no less than four panes separated from one another by air layers. This protects the windows against fogging at low temperatures. The chambers are fitted out with hatches or doors which open to the outside. The pressure chamber is provided with a small antechamber (sluice) having two doors for purposes of entering the chamber when a vacuum exists on the inside; these two doors consist of an outside door and an inside door leading into the main chamber. The experimenter entering the sluice may balance the pressure between the chambers by means of a valve and open the inside door.

Low temperatures (−70°C) in the heat and pressure chambers can be

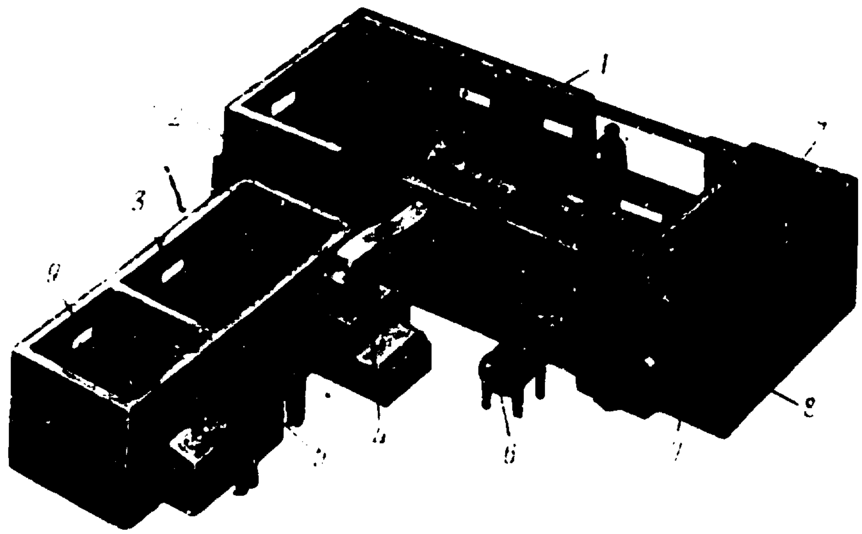


Fig. 228. Over-all view of high-altitude laboratory (heat and pressure chamber) at the "Wright" Science Research Center in the vicinity of Dayton (USA). 1) Main chamber; 2) door; 3) small chamber; 4) single-position (difference) chamber; 5) control panel; 6) animal chamber; 7) steel plate; 8) steel frame; 9) antechamber.

achieved by means of ammonia or freon cooling units or by means of evaporators (radiators) which are positioned inside the chamber. For rapid cooling, turbine-driven compressed-air refrigeration equipment is employed.

High temperatures (100°C and higher) are attained by means of screens heated electrically and positioned inside the chamber about the work position of the individual conducting the test.

Ozone is obtained by quiet electric discharges. The evacuation of air from the heat-pressure chamber is carried out by means of vacuum pumps. A feature of pressure chambers intended for the testing of high-altitude apparatus and equipment is the fact that in order to maintain a given "altitude" in the chamber it is necessary continuously to evacuate the oxygen supplied for human breathing.

The oil vacuum pumps are made explosion proof by diluting the evacuated gas with air or nitrogen so that the oxygen content does not exceed 45%.

Heat-pressure chambers intended for the training of pilots are generally fitted out with small VN-1 type vacuum pumps (power, 2.8 kw), developing an "altitude" in the chamber of 12,000-13,000 meters. VN-6-type pumps (power 20 kw) make it possible to achieve an "altitude" of up to 30 km. To attain an "altitude" in the pressure chamber of the order of 50-100 km (with an oxygen supply for breathing) requires the simultaneous operation of a great number of powerful vacuum pumps.

Communications with the subject in the heat-pressure chamber are carried out by means of telephone. In addition, the subject has emergency sound and light signals at his disposal. For purposes of measuring parameters through the wall of the heat-pressure chamber, numerous wires and tubes of various diameters have been led in.

Each pressure chamber is fitted out with an emergency valve for rapid leveling off of the pressure between the chamber and the "ground." The valve is under the control of a doctor who maintains continuous visual observation of the subject.

All machinery — refrigeration compressors, vacuum pumps, electric generators, transformers — as a rule are housed in an adjacent insulated unit with a pressure chamber so as to prevent the noise from this equipment from interfering with the conduct of the tests.

The purpose of the tests in a heat-pressure chamber is the integrated examination of individual high-altitude equipment and oxygen breathing systems under conditions affording the greatest simulation of high-altitude flight conditions.

The heat-pressure chamber test program for high-altitude space pressure suits or G suits with ventilated clothing is generally as follows.

A. Without subject (with dummy)*

1. Inflation of space pressure suit, helmet, or tensioning devices

of suit with test excess pressure of 150% of the maximum operating excess pressure (this test is preceded by a test of the static strength margin by inflating a test specimen to destruction).

2. Checking of the airtightness of the equipment and determining the magnitude of gas leakage losses.

3. Checking the operation of pressure regulators and determining the magnitude of the excess pressure developed in the helmet (in the shell) at various altitudes.

4. Checking the hydraulic resistance of the ventilation system and the distribution of the ventilation air through the suit.

5. Checking the oxygen and carbon-dioxide content in the inspired air and the resistance to breathing. This test is carried out by means of mechanical lungs with which various magnitudes of lung ventilation are developed: generally 7.5, 15, and 30 liters per minute (the carbon dioxide is supplied from a tank through a pressure-reduction valve and a calibrated nozzle in a quantity corresponding to that cited in Fig. 170).

6. Checking the emergency oxygen supply and the oxygen flow rates for various magnitudes of lung ventilation (on artificial lungs) with connected and disconnected air intake automatic units.

7. Checking oxygen concentration in helmet during rapid-ascent regime.

8. Testing for difference (explosive decompression) by measuring dynamics of change in suit and helmet pressure and oxygen concentration in helmet after 1 minute after pressure difference [drop].

B. With test subject

1. Checking ease and time required for donning of equipment and mobility of individual with excess pressure in suit.

2. Checking temperature regime, level of heat sensation, required

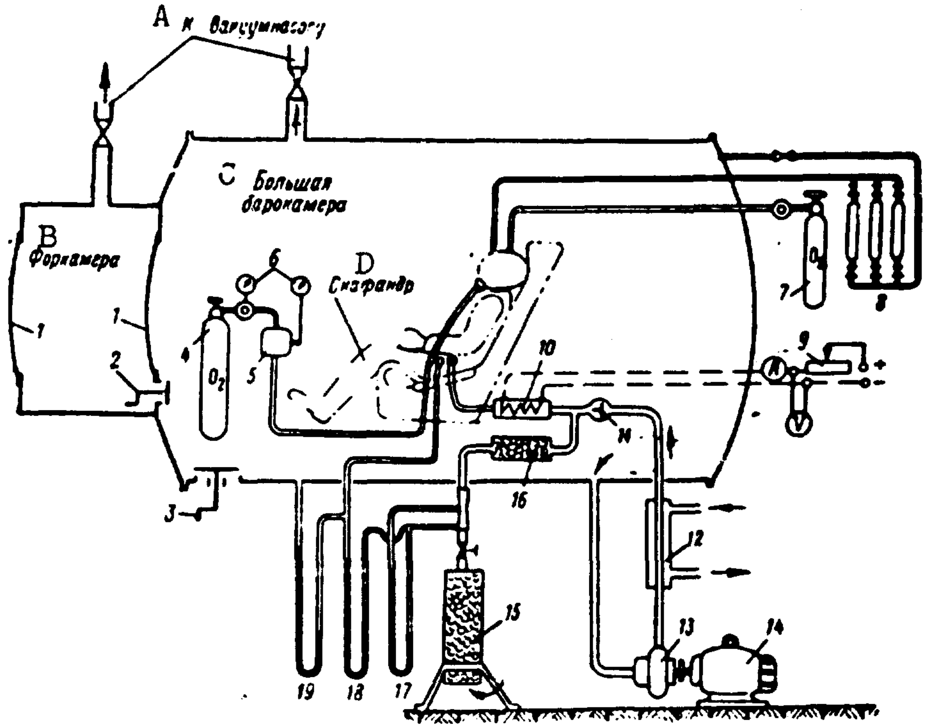


Fig. 229. Diagram of space pressure suit (ventilation-type) test in pressure chamber. 1) Entry doors; 2) valve for pressure balancing; 3) valve for rapid "descent"; 4) oxygen tank; 5) stationary oxygen unit; 6) oxygen-unit monitoring instrument; 7) emergency oxygen tank; 8) burettes for sampling of air; 9) rheostat with ammeter and voltmeter; 10) electric heater; 11) return-flow valve; 12) refrigeration unit; 13) supercharger; 14) electric motor; 15) drier; 16) freezing unit for removal of moisture; 17, 18, 19) manometers, respectively, for measurement of flow rate, resistance, and excess pressure in space pressure suit. A) To vacuum pump; B) antechamber; C) large pressure chamber; D) space pressure suit.

air and oxygen flow rate for given maximum duration.

3. Checking visibility and nonfogging of face plate.

4. Checking pressure in helmet and shell.

5. Checking oxygen and carbon-dioxide concentration and resistance to breathing.

6. Simulation of parachute descent (i.e., checking work of oxygen-breathing system when supply is taken from parachute unit).

7. Testing for explosive decompression.

Figure 229 shows a typical diagram of pressure and flow-rate measurements during space pressure-suit tests in a heat-pressure chamber [30].

By means of the burettes shown in this diagram air samples are taken from the helmet for subsequent analysis in a Holden apparatus which yields average values for the O_2 and CO_2 contents. To obtain the true values for these quantities, corresponding to the inspiration phase, the samples are taken during the inspiration phase in evacuated burettes. For this another experimenter joins the first in making the pressure-chamber ascent. In recent times electron-optical gas analyzers have appeared on the scene and these show the current value of oxygen and carbon-dioxide concentration, thus significantly speeding up and simplifying the conduct of the investigations.

The measurement of resistance to inspiration and expiration is carried out with a cup (single-knee) water manometer or by means of electronic manometers.

Simultaneously with the measurement of the engineering characteristics, an objective inspection of the condition of the organism is carried out. For this purpose the subject is measured for pulse and respiration rates, skin and body temperature, as well as the oxygen saturation of the blood (by means of a sensing element connected to the earlobe), the arterial pressure of the blood and the biological currents of the brain with an electroencephalograph (the last two types of measurements are not widely performed). The continuous monitoring of the oxygen saturation of the blood with an oxymeter has significant advantage over the analysis of the alveolar air for oxygen, since it shows the state of the organism at the given instant of time; however, each helmet is not provided with a sensing element for this instrument. Tests for explosive decompression are carried out either in a pressure chamber in which the volume of the antechamber is smaller than the volume of the main chamber by a factor of at least 40-50, or these tests are carried out in a special installation. In the first case, there must be a large instant-opening valve between the antechamber and the main chamber. The subject moves into the antechamber; a predetermined expansion occurs in the main chamber, and the valve is then opened.

In the majority of cases the installation designed to test pressure differences is made as a unit separate from the heat-pressure chamber. A strong single-position cabin [cockpit] 1-1.5 m^3 in volume is connected by means of a short large-diameter tube to a space exhibiting a volume of the order of 100 m^3. A throttle is installed between the cabin [cockpit] and the space and this device must be capable of being opened instantaneously by means of pneumatic cylinders. The space is connected to a vacuum pump and the required rarefaction is produced. As the throttle is opened the pressure in the cockpit cabin becomes close to the initial pressure in the space. Thus, for example, if we are dealing with a cockpit 1.5 m^3 in volume and a space of 100 m^3, the initial pressure in the cabin being about 267 mm Hg (8000 m) and 8 mm Hg (30,000 m) in the space, after the opening of the throttle the pressure will be the following:

$$p = \frac{267 \cdot 1.5 + 8 \cdot 100}{1.5 + 100} = 11.8 \text{ mm Hg } (\sim 28 \text{ km}).$$

In order to ensure the safety of the high-altitude tests, an additional hose is attached to the airtight helmet to provide for a supply of oxygen from a separate tank in the case the main system fails to function. The oxygen valve is mounted on the control console of the physician in charge.

Of the remaining measures associated with safety engineering, our attention should be concentrated on the following:

1. Experiments with a human being must necessarily be preceded by engineering [unmanned] ascents and pressure drops. In this case, all

electrical systems must be connected and tested out.

2. In the installation of the oxygen system cleanliness must be rigorously maintained – remember that greases and oils are capable of spontaneous combustion and detonation if permitted to come into contact with oxygen compressed to 6 atm and higher.

3. In the event of cold-exposure tests oxygen tanks must be stored in the heat-pressure chamber in advance in order to remove moisture through freezing. The charging of parachute units must be carried out by transferring from cooled tanks or through a moisture drier. Parachute oxygen equipment covered with dew must be dried before being placed into the heat-pressure chamber.

4. Electric heaters must have heat-sensitive switches that operate automatically on overheating (for example, upon cessation of the air supply). The air lines must be connected to the electric heater by means of nuts. Durite cannot be used for the connections.

§6. AUXILIARY EQUIPMENT

1. The dummy. Of the auxiliary equipment used for testing of ejection seats, the most important is the dummy. The dummies used in these tests must be anthropometric, i.e., as much like a man as possible in terms of weight, size, posture, moment of inertia, and mobility of head and extremities.

In terms of weight and size dummies differ with respect to "percentage." For example, the term a "90% dummy" indicates that 90% of the flight crew is lighter in weight and smaller in size than the dummy, and that only 10% of the crew is greater in size and larger in weight.

We generally encounter two types of dummies, i.e., assembled from orthopedic parts (artificial arms, legs, etc.), with posture and weight achieved by positioning special weights in the dummies, or rubber dummies with a jointed skeleton. The rubber dummies are better, since to some extent they also simulate the elasticity of the human body.

During the course of tests, particularly in he case of flight or rocket-sled tests, the accelerations to which the dummy is subjected must be measured.

In testing for the effect of ram pressure it is necessary to r ure vibration, particularly the vibration of the dummy's head. For this reason chambers are built into the head and chest of a dummy t hold automatic recording units or sensing elements for a telemetry system.

2. Installation for the reproduction of dynamic application of load. The schematic diagram of such an installation is shown in Fig 230.

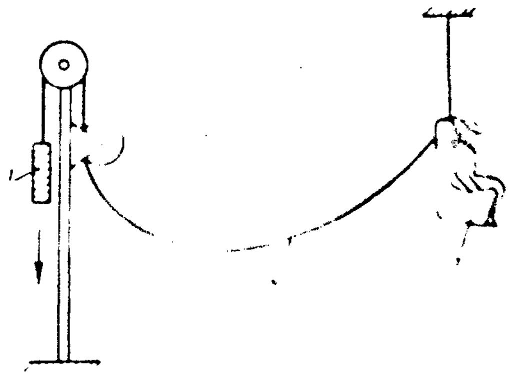


Fig. 230. Diagram of installation for reproduction of dynamic loads. 1) Falling load; 2) capron cable with initial slack; 3) seat with dummy being tested.

A weight falling from a given height and acquiring kinetic ene: elongates an elastic cable (generally, a capron strip) connected to the point on the seat being investigated and thus produces a dynamic load at the points of cable attachment. Varying the course of the f: fall of the seat, the mass of the weight, and the rigidity of the cable, it becomes possible to develop a load which in terms of magn

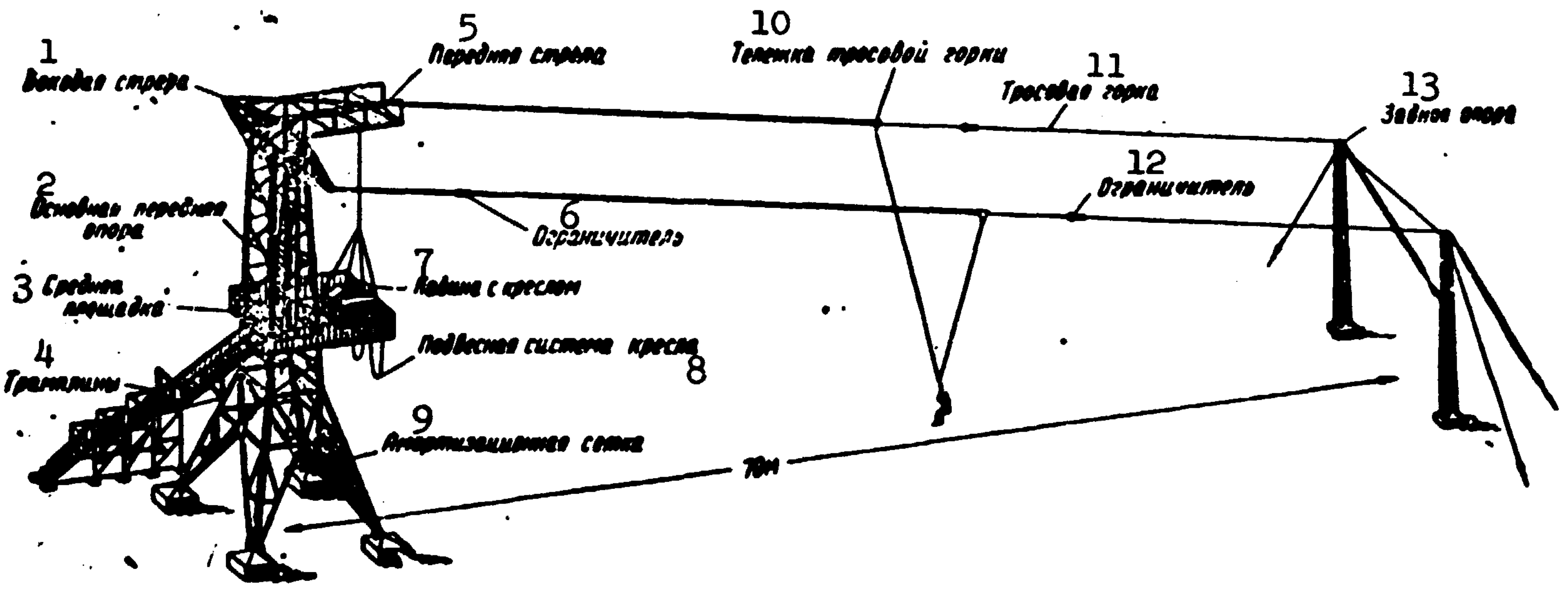


Fig. 231. Diagram of ground training installation. 1) Side boom; 2) main forward support; 3) center platform; 4) spring boards; 5) forward boom; 6) limiter; 7) cockpit with seat; 8) seat suspension system; 9) cushioned net; 10) runner of cable slope; 11) cable slope; 12) limiter; 13) rear support.

Fig. 232. Installation of small catapult over cliff.

tude and nature of change is similar to the load encountered in nature. Since all these dynamic loads act on the seat during its free fall, the seat itself during the course of these tests is suspended from cables. Occasionally in checking the releases of parachute systems for example, it is necessary to apply simultaneously dynamic load and vibrations. In this case the vibrator producing the vibrations is mounted directly on the seat.

3. Ground training installation with cable slope. The diagram of

this training installation is shown in Fig. 231. A training installation of this type makes it possible to eject people and dummies with an explosive cartridge of reduced size in the firing mechanism. After ejection the individual separates from the seat and slides by means of a suspension system along the cable slope, gradually reaching the ground. The seat, attached to the top of the training installation, falls into a cushioned net. Although such a training installation is intended for the training of a flight crew, it can also be used to check the operation of a number of seat units.

4. The small catapult, which reproduces ejection from cabin [cockpit] from a standing position. This catapult is used to check the operation of firing mechanisms (the maximum G forces and the initial ejection velocity is checked). Nets similar to those shown in Fig. 226 can be employed to recover the seat in this case. If the conditions of the terrain permit, a catapult of this type may be installed at the edge of a cliff (Fig. 232). In this case, the seat can be recovered by means of a parachute system. During the course of these tests it is also possible to check the operation of the parachute system and its releases, the separation of the dummy from the seat, etc. These tests are not identical to flight tests because there is no horizontal velocity, but nevertheless they yield valuable results.

5. Deep pool to test jettisoning of canopy when submerged. Earlier we spoke of the case of underwater ejection. For aircraft flying over water rescue when submerged is to some extent a theoretical case. Investigations in o the jettisoning of a canopy for this purpose are carried out in a deep pool.*

Manuscript Page No.	[Footnotes]
172	"Popular Science," 1956, December, page 77. "Aeronaut. Eng. Rev.," Vol. 15, 1956, December. "Aviation Week," 1955, April, pages 35-36; Vol. 67, 1957, No. 26, pages 83-85. "American Aviation," 1955, April, page 32.
174	Rocket sleds are a relatively new form of test equipment whose area of application is by no means limited to testing of ejection seats. Further on, an entire section is devoted to these sleds.
191	A mannequin is required in a number of cases in order to reproduce the free volume on whose magnitude depends the stresses in the case of a pressure difference, the CO_2 content, etc.
200	We know, for example, of tests conducted by the Douglas Company at the experimental center in El Segundo in a 7.3 m deep pool. The jettisoning of canopies at depths of 4.5 meters was tested, i.e., at an excess pressure of about 0.5 gauge pressure (Naval Aviation News, 1956, October).