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SPACECRAFT UTILIZING THE LIFTING REENTRY TECHNIQUE

PART I. REENTRY AND RECOVERY OF THE  
SOVIET MANNED SPACE VEHICLES

Comprehensive Analysis  
Based on Soviet and Soviet  
Bloc Open Literature

UNEDITED ROUGH DRAFT

AID Work Assignment No. 52

PREPARED

by

A. DOLGICH

Aerospace Information Division  
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## FOREWORD

This report, prepared in response to AID Work Assignment No. 52, contains material drawn from the Soviet and Soviet-bloc open literature published in connection with the launchings of all the Soviet space vehicles. Section A contains a comprehensive analysis of some data discussed in Sections, B, C, D, E, F, and G. The analysts' conjectures on possible design principles utilized in the Vostok reentry systems, contained in Item 6 of Section A, are felt to be the most significant material in this report.

## Table of Contents

### Foreword

|  |           |
|--|-----------|
| <b>Section A. Brief Discussion and Analyst's Conclusions and Conjectures .....</b>                           | <b>1</b>  |
| 1. General Data on Reentry and Recovery .....  | 1         |
| 2. Setting the Vehicle in the Orbit .....  | 2         |
| 3. Reliability of Vostok-Type<br>Spaceships .....  | 3         |
| 4. Vostok-Type Spaceship Orientation<br>and Control Systems .....  | 3         |
| 5. Deceleration by Retroengine Unit .....  | 5         |
| 6. Possible Design Principles Used<br>in Vostok Reentry Systems .....  | 6         |
| <b>Section B. General Data on the Structure<br/>of Vostok-Type Spaceships .....</b>                          | <b>12</b> |
| 1. Similarity in Design and Mission<br>Principles of the Soviet Spaceships .....                             | 12        |
| 2. General Configuration of Vostok-<br>Type Spaceships .....   | 14        |
| 3. Reliability of Vostok-Type Spaceships .....   | 14        |
| <b>Section C. Descent of a Spaceship From Orbit<br/>to the Sensible Atmosphere .....</b>                     | <b>17</b> |
| 1. Orientation System .....  | 17        |
| 2. "Space Compass" (Orbit<br>Navigation Device) .....  | 20        |
| 3. Retroengine Unit .....  | 22        |
| 4. Deceleration by Retro Power Unit<br>and Free Descent of a Spaceship<br>Along the Reentry Trajectory ..... | 24        |
| <b>Section D. Descent of a Spaceship Through<br/>the Sensible Atmosphere .....</b>                           | <b>28</b> |
| 1. High Temperature and Overload Phase .....   | 28        |
| 2. Characteristics of a Shock-<br>Wave Front .....   | 29        |
| 3. Heating of Aerospace-Vehicle Surfaces .....   | 35        |
| 4. Cosmonauts' Impressions of Reentry .....  | 37        |
| 5. Aerodynamic Methods for Decelerating<br>Space Vehicles in the Sensible<br>Atmosphere .....                | 38        |

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|  |           |
|--|-----------|
| <b>Section E. Protection of Aerospace Vehicles</b> |           |
| From Overheating .....                             | 40        |
| 1. Material Used for Aerospace-                    |           |
| Vehicle Walls .....                                | 40        |
| 2. Protection of Space Vehicles by                 |           |
| Ablation and Sublimation .....                     | 48        |
| 3. Cooling Systems .....                           | 52        |
| <b>Section F. Landing Systems .....</b>            | <b>55</b> |
| 1. Two Landing Methods for                         |           |
| the Cosmonauts .....                               | 55        |
| 2. Landing Method for Vostok-Type                  |           |
| Spaceships .....                                   | 56        |
| 3. Landing Methods for Cosmonauts .....            | 58        |
| 4. Space-Flight Command and                        |           |
| Communications Network                             |           |
| (Recovery Phase) .....                             | 61        |
| <b>Section G. Lunar Flights .....</b>              | <b>67</b> |

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## Section A. Brief Discussion and Analyst's Conclusions and Conjectures

### 1. General Data on Reentry and Recovery

The diagram and chart shown in Figures 1 and 2 are based on the comprehensive analysis of material found in Soviet open literature published in connection with flights of the Vostok-type spacecraft.

The material discussed in this report and partially represented in Figures 1 and 2 has been grouped according to the reentry and recovery phases, including orientation, deceleration by the retroengine unit, free descent, deceleration by the atmosphere, and landing of the spaceship.

Preparation of the spaceship for reentry begins at a distance of about 18,000 km from the landing point, and the reentry and recovery phase lasts about one hour. The retro-engine unit is fired at a distance of about 8000 km from the landing point, and the recovery vehicle reaches the earth's surface in about 30 minutes or less. To transfer the spaceship from orbit to a descent trajectory, it is sufficient to reduce the orbital velocity by about 40--100 m/sec; thus, the ship enters the atmosphere at a velocity only slightly less than orbital velocity.

The spaceship enters the sensible atmosphere at an altitude of about 90--100 km, and it reaches the earth's surface in about 20 minutes. The high-temperature and overload phase lasts about 15 minutes, when the spaceship speed has been decelerated by the brake flaps and steel-strip parachute. Peak reentry overloads of about 10 g's occur at an altitude of about 50 km. During the high-temperature and overload phase, the spaceship's velocity is reduced from about orbital velocity to a speed of about 200 m/sec, and the maximum temperature of the nose cone reaches about 1000°C.

The cosmonaut and spaceship are landed by aviation parachute system, each of which consists of three parachutes. The cosmonaut is ejected from the spaceship cabin at an altitude of about 7 km and reaches the earth's surface at a rate of about 8--5 m/sec. The spaceship parachute system is switched on at an altitude of about 4 km,

and its main parachute deploys at an altitude of less than 3 km. The ship lands at a speed of about 10 m/sec.

Analysis of Soviet literature does not lead to the conclusion that the successes in Soviet space technology, emphasized by Soviet authors, can be attributed to the discovery by the USSR of some special type of rocket-engine fuel or new heat-resistant materials used in the structure of engines and recoverable vehicles. Analysis does indicate that a part of this success is due to the special organization of the heat-exchange process. Discussing the development of the space engines used for launching Vostok-1 and Vostok-2, the Chief Designer of these engines states that priority in research was given to the study of "highly forced" combustion processes which basically determined the success of the entire project. [1]. Several indications were found showing that hot gas is removed from the walls of the structure by a relatively cool gas flow. In this report, the application of this method of protection of a body from overheating is demonstrated in Fig. 15, where a relatively cool gas flow generated by the retroengine unit removes the hot gas of the shock wave from the ship's nose.

Figures 3, 4, 7, and 14 have been taken from East German source 2; Figures 6, 8, 10, 11, and 12, from Russian sources 3, 4, 5, and 6; Figure 9, from Czechoslovakian source 7; Figure 5, from Rumanian source 9. Figures 13 and 16, from Hungarian sources 10 and 8; and Figures 1, 2, 15, and 17 were compiled by the analyst.

## 2. Setting the Vehicle in the Orbit.

Analysis of Soviet open literature indicates that all Soviet space vehicles were launched by a carrier rocket developed by one organization under the supervision of one person. Some sources give indications which make it possible to conclude that the Soviet space vehicles were launched by three-stage carrier rocket systems as shown in Fig. 3.

From Soviet sources it is known that the carrier rockets used for launching the Vostok-type spaceships were equipped with six liquid-propellant engines developing a total of 10,000,000 hp with a maximum thrust of 600 tons.

However, according to an East German source [2], the estimated thrust of the Soviet carrier rocket used for launching the Vostok-1 and Vostok-2 was 750 to 1000 tons, with the launch weight of this carrier rocket system well over 500 tons. The same source states that the carrier rocket tested in the Pacific Ocean on 14 September 1961 gives rise to the conjecture that it was a system capable of launching a 10-ton payload.

### 3. Reliability of Vostok-Type Spaceships.

The Vostok-type spaceship consists of two basic units: the cosmonaut's cabin and the instrument section. The retroengine unit and the orientation systems are located in the instrument section, which is separated from the cabin during reentry.

The Vostok-type spaceship is equipped with systems for saving the cosmonaut in any emergency situation which could be foreseen at any point during launching, reentry, or recovery. The automatic reentry and recovery systems of the spaceship are backed up by manual control. In the event of automatic and manual control system failure, over a period of ten days the ship will of itself gradually enter the dense layers of the atmosphere and descend.

The more essential systems and components of the Vostok spaceship were duplicated and even triplicated. Reserves of food, water, regeneration system reagents, and electric power were included in sufficient quantity to sustain a cosmonaut for a period of 10 to 12 days. In case of an emergency situation arising during launching or reentry, a bright light flashes on a screen; the cosmonaut pulls a lever which activates a seat-ejection system. The pilot's seat is equipped with a portable emergency kit, as well as with radio and direction-finding equipment. The Vostok-type spaceships are suitable for repeated flights.

### 4. Vostok-Type Spaceship Orientation and Control Systems

Spacecraft orientation and control systems have been used in the USSR since 1959, beginning with the launching of an interplanetary station towards the moon. Orientation of Vostok-type ships is carried out automatically, using the sun as a reference, and manually, using the earth.

The orientation system of the Vostok-type ships consists of sensitive optical and gyroscopic sensors, gas rudders, compressed-gas tanks, a "VZOR" optical orientation device, a special control stick with spacecraft angular-velocity sensors, and the orbit navigation device "space compass."

The "VZOR" optical orientation device is used by the cosmonaut in manual control for determining the position of the ship relative to the earth. It is mounted on one of the three cabin portholes and consists of two ring-shaped mirror reflectors, a light filter, and glass with a reticle. The sun's rays coming from the line of the horizon strike the first reflector, then pass through the porthole glass to the second reflector, which directs them through the glass with the grid to the cosmonaut's eye. When the ship is properly oriented, the cosmonaut sees an image of the horizon in the shape of a concentric ring, and the direction of the "run" of the earth's surface coincides with the course line of the grid. Deviation of the ship from this position is corrected by the cosmonaut, using the control stick.

To determine the location of the spaceship, in the cabin section where the cosmonaut finds himself are three portholes, and on the instrument board is a small "space compass" navigation device. The space compass is a silver box, two times smaller than an ordinary Soviet television set. This device, which is in its way a computer, takes only 0.3 w of electric power and can operate from a pocket battery. The space compass has been used for determining the longitude and latitude of the spaceship, the number of completed orbits, and the place for landing. The navigation device is installed in the cabin of the ship in the upper left-hand corner. On the instrument board of the ship is seen a finely drawn globe located under the spherical glass. On the spherical glass there are two large and small circles with a reticle, the smaller circle within the larger one. The globe is rotated at exactly the same angular velocity as the earth and has two settings, the "orbit" setting and the "landing" setting. The orbit setting shows the location of the ship relative to the earth's surface during the orbit flight, and the location area is seen under the reticle of the large circle. The landing setting shows the point at which the ship would land had the cosmonaut begun deceleration at that moment, and which is seen through the small circle on the spherical glass. To change the globe's setting from "orbit" to "landing," a switch is thrown, causing the globe to skip to a new position. A small opening, like the speedometer of

the "Moskvich" automobile, shows the number of orbital passes.

The orientation system is switched on at a distance of about 18,000 km from the landing point about one hour before landing of the spaceship's cabin (64 min for Vostok-1 and 55 min 44 sec for Vostok-6).

##### 5. Deceleration by Retroengine Unit.

Deceleration of the spaceship from the apogee is much more economical on fuel than deceleration from the perigee. For the fourth ship-satellite, the deceleration from the apogee gives more than 40 percent savings in fuel in comparison with deceleration from the perigee. But, actually, fuel economy is far from being always the deciding factor.

The sources used for this report do not give definite data on the Soviet spaceship's speed during orbital flight and reentry. Analysis of data mentioned by the Soviet writers make it possible to conclude only that the retro-engine unit decreases the speed by relatively small value, and the spaceship approaches the dense layers of the atmosphere at a speed of about the first cosmic speed. Theoretically, to cause the descent of the Vostok-type spaceship required decreasing the flight speed by about 0.050 km/sec. In reality, however, the same Soviet recoverable space vehicles were caused to descend probably by decreasing the speed by about 0.5 km/sec.

The weight of the retroengine unit depends upon the total decrease in speed, regardless of the number of starts and the duration of operation. For orbiting ships flying at altitudes attained by the Vostok-3 and Vostok-4, it is sufficient to decrease the speed by 40 m/sec for them to descend below 100 km. Such a change in speed requires a retroengine unit which comprises only 1 to 2% of the ship's weight. To change the speed of a spaceship by 100 m/sec, it is necessary to have a power unit which comprises from 3 to 6% of the ship's weight (cabin, payload, cosmonauts), and to change the speed by 2 km/sec, it is necessary to have a fuel reserve equal to 40 to 60% of the ship's weight. The weight of the entire retro-engine unit comprises 50 to 80% of the ship's weight.

## 6. Possible Design Principles Used in Vostok Reentry Systems.

Fig. 15 has been compiled by the analyst after a comprehensive analysis of the material used in this report. Items 1, 2, and 3 shown in the figure were mentioned by several sources stating that the Vostok spaceship consists of two main sections: the cabin section (1) and instrument section (2), with the retroengine unit located in the instrument section.

From the sources analyzed it follows that the retroengine unit contains one or several liquid-propellant engines located in the rear of the spaceship. However, no textual material was found mentioning the location of the retroengine unit discharge nozzles. A TASS report [11] and another Soviet source [3] contain illustrations in which the discharge nozzles of the retroengine unit are located in the rear of the Vostok spaceship. However, an East German source [2] contains illustrations (see Figs. 4 and 7) in which the discharge nozzles of the retroengine unit are depicted as being located in the front of the spaceship. There is no reason to suppose that, in his book, East German specialist Hoffman changed the concept of rearward discharging nozzles, as published first in TASS, without a purpose; it is possible that he changed the TASS concept in order to be more accurate. Therefore, for the purposes of this report, reference 2 is considered as a more authoritative source regarding retroengine discharge nozzle location (see items 4 and 5 of Fig. 15), and the nozzles are consequently shown in the front part of the spaceship.

A reentry system with retroengine unit bow nozzles is more logical than a system employing stern-mounted retroengine unit discharge nozzles. A description of the retroengine unit with bow nozzles serves well to clarify several indications by Soviet specialists relating to reentry principles which have remained unclear when analyzed in the light of a retroengine unit with stern nozzles. The first advantage of a retroengine unit with bow nozzles is that it is not necessary for the spacecraft to undergo two 180-degree maneuvers: one in orbit before firing the unit and again on the descent trajectory before reentry. This conclusion by the analyst is based mainly on Figures 4 and 7. In addition, it is supported partly as follows: No textual information was found in the sources

used for this report indicating that the Vostok spaceships travelled with the nose to the rear while in orbit or during descent. On the contrary, the analysis of material relating to ground-based cosmonaut training in the ship, the discussion of flights by the cosmonauts, and descriptions of the operation of the orientation system by various writers indicate that in orbit the spaceship maintained a nose-to-front attitude.

The second principal advantage in a retroengine unit with bow nozzles is that during the reentry sequence, the retroengine unit may be used twice: once in orbit and once in the high-temperature zone. This conclusion is based mainly on an article by Professor V. V. Dobronravov [12], from which it follows that two methods are employed in the reentry of a spaceship: retrograde thrust and velocity damping in the atmosphere. In addition, the above conclusion is supported partly by reference 13, from which it follows that the Vostok's instrument section (in which the retroengine is located) separates somewhere near the end of the high-temperature and overload portion of the reentry trajectory (see Figs. 1 and 2). It is not logical to suppose that in the atmosphere the retroengine unit operates for the purpose of reducing the speed of the spaceship, because, as mentioned by I. A. Merkulov [14], to change the speed by 2 km/sec, it is necessary to have a fuel supply equal to 40 to 60% of the ship's weight. In the analyst's opinion, in the high-temperature phase of reentry, the retroengine unit is used not for reducing the ship's speed, but to push away the shock wave (see item 6 of Fig. 15) and to reduce the heating of the spaceship structure. From this point of view, it is reasonable to conclude that the spaceship is equipped not with two discharge nozzles as shown in Figures 4 and 7, but with four peripherally-located discharge nozzles (item 4, Fig. 15), and one centrally-located discharge nozzle (item 5, Fig. 15) in the nose. Reference 3 states "The shell of the fore body of the ship is made with a double wall, like the jacket of an internal combustion engine. The coolant is pumped into the jacket space. The surface of the rocket's cone is porous [3].

According to reference 15, "liquid cooling through the pores of the shell is possible, although there is a danger of the pores becoming choked." [15]. Therefore, some writers state that gas may be used in a porous cooling system instead of liquid. From these statements it might be concluded that in the porous cooling system shown in Fig. 15, the gas produced by the retroengine unit might be used.

If this is so, then the gas flowing through the porous nose cone separates the boundary layer from the cone while the gas flow from jets 4 and 5 (Figure 15) moves the shock wave 6 (Figure 15) to position 7 (Figure 15).

It does not necessarily follow that the gas produced by the retroengine unit (3) flows to the nose cone along the four channels shown in Fig. 15. It is possible that the ship's shell is made with a double wall and the gas going from the engine 3 to the nose cone flows through the jacket space. In this case, the gas flowing through the jacket may be considered as protection for the cosmonaut's cabin, since the discharge gas temperature for liquid-propellant engines does not exceed 2000°C [16], i.e., it is much lower than the gas temperature on the outer surface of the ship's shell during reentry. The spherical shape of the cabin, as shown in Fig. 15, has been discussed in a 1961 AID report [17], which is based on several open sources, including a TASS report [11]. The spherical cabin requires a relatively small contact area between the cabin wall and ship's shell; this decreases the degree of heat transfer from the hot outer surface of the ship to the cabin.

Several sources state that internal cooling systems utilizing water may be used in space vehicles, but the sources do not indicate in what part of the vehicle such systems are used.

The concept of locating the discharge nozzles in the front of the spaceship is supported additionally by Titov's discussion of the "fireflies" or the "phenomenon of small luminous dots floating past the porthole of the spaceship" during his orbital flight. Titov explained their origin as follows: "...during scavenging (cleaning the engine), burnt gases and liquids under conditions of weightlessness turn into drops, scatter and luminesce in the sun's rays..." [47] From Titov's discussion it follows that the small dots originated in the engine discharge nozzles, since (it is logical to suppose) only these parts of the retroengine unit are exposed during weightlessness, but he doesn't mention the direction in which the dots floated. This blank in Titov's description was made for in the Bykovskiy and Tereshkova report [19], in which Bykovskiy discusses the dots stating, "their movement appears as if they are leaving the ship or the ship is passing by them."

The stabilizing ring (9), attitude control nozzle chambers (10) and gas flows (11) and (12) have been drawn in Fig. 15 based on Figures 9 and 14b. The operation of these components is not discussed in the references; however, in this report, a brief discussion will be given below based on analysis of Fig. 14b.

Analysis of reference 2 leads to the conclusion that illustrations 14a and 14b, appearing on the same page in the reference, represent the beginning and the end of a Vostok flight. However, the author doesn't give a textual explanation of these pictures. In the reference, illustration 14b shows a Vostok spaceship, the nose portion of which is surrounded by billows of smoke, while its nozzles, located on the stabilizing ring, discharge a forward flow in the direction of the nose portion of the ship. It seems that the billows of smoke have been reflected in the same manner as the smoke issuing from carrier rocket engines when fired on the ground. From this discussion it follows that for a logical explanation of Fig. 14b there is only one probable assumption which can be made: the Vostok is equipped with retroengine unit bow nozzles as is depicted in Fig. 15, and Fig. 14b shows the Vostok in the reentry mode in which the gas flows generated by the retroengine unit are being reflected from the shock wave.

Fig. 14b shows very strong gas flows discharging from the stabilizing ring. It looks as though these flows are able to maintain a proper reentry angle with high accuracy. The gas flows (12) shown in Fig. 15 are based on Fig. 9. These flows may be used after the ship has attained orbit or during orbital flight when it is necessary to increase the ship's speed by a small value.

On the basis of Fig. 10 [5], it is possible to conclude that the pilot's seat shown in Figures 9 and 15 is in the launching position. During the deceleration of the ship in the atmosphere, the cosmonaut should be in a reentry position, i.e., with his back to the front of the ship. The pilot's seat in Fig. 15 might be changed from the launching position to the reentry position by rotating the spherical cabin as shown in Fig. 16 [8], item 3 of which indicates special equipment for this purpose. The position of the cosmonaut can be changed also by reversing the seat without the necessity of rotating the entire spherical cabin. This conclusion by the analyst

is based on an indication found in a TASS report [11]. Discussing Vostok design principles this source states, "The cosmonaut situates himself in the ship-satellite's ejection seat, which serves as his work area during flight and is used for ship egress by the cosmonaut in an emergency. The "pilot's seat has been so positioned that overloads act on the cosmonaut in the most favorable direction (chest to back) during launching and reentry." [11]. From this statement it follows that only the seat position determines the direction in which launch and reentry overloads act on a cosmonaut and not the rotating of the spherical cabin or the entire ship. If this is true, then changing the direction in which the cosmonaut faces during launching and reentry position can be done by rotating the pilot's seat 180 degrees. Fig. 17 has been made by the analyst on the basis of several open sources and originally appeared in AID Report 61-101 [17]; this figure indicates that the pilot's seat can be rotated about its lengthwise axis.

Fig. 16 is a reproduction of a color sketch of a spaceship with a spherical cabin published in *Tudomány es technika* [8], a Hungarian popular science periodical. Although the sketch is not specifically identified as the Vostok-1, it accompanies an account of Gagarin's flight. The weight given for the spaceship is 4725 kg, the same as the weight officially announced for the Vostok-1.

Analysis of the various illustrations depicted in Fig. 16 leads to the conclusion that the Hungarian source [8] shows the recoverable capsule without cone (center illustration) and the entire ship with cone in orbit (upper and lower illustrations); these are similar to the ships shown in Figures 3 and 4. The lowermost illustration in Fig. 16 depicts the recoverable capsule in three modes: with gas flow, with gas flow and aerodynamic braking, and with parachute. This illustration supports the main reentry principle discussed above that during the reentry of a Vostok spaceship, the retroengine unit is used twice: once in orbit and once in the atmosphere.

The periodical *Znaniye-sila* [20] is one of the few Soviet sources to use the word "capsule" to describe the recoverable cabin of a spacecraft. This source does not give any information relative to the nose-coneless

capsule of the type shown in Figure 16. At the present time, the principle of a nose-coneless recoverable capsule, like the one shown in Fig. 16, cannot be used as basic material in extrapolating Vostok reentry systems, since the nose-cone-type recoverable cabin (Fig. 15) with the retroengine unit located in the instrument section is supported by several Soviet sources. It is possible that in the future, additional information will become available on the nose-coneless recoverable capsule, and the design principles shown in Fig. 16 may be of use as basic material in the extrapolation of the Vostok design.

SECTION B. GENERAL DATA ON THE STRUCTURE  
OF VOSTOK-TYPE SPACESHIPS.

1. Similarity in Design and Mission Principles of Soviet  
Spaceships.

This section contains material in support of statements  
which appeared previously in AID publications:

A. All the Soviet space vehicles and carrier rockets  
were developed under the supervision of one person, who in  
Soviet literature is referred to as the "Chief Designer of  
Space Vehicles," or the "Chief Designer."

B. The structure of all the Vostok spaceships is similar  
to that of the five previous Soviet ship-satellites launched  
in 1960-1961.

C. All the ship-satellites and manned Vostok spaceships  
were launched and recovered according to the same program.

The prime significance of these statements lies in the  
fact that they make it possible to relate previously published  
information on the ship-satellites to the Vostok spaceships.  
Several statements showing various similarities in Soviet space  
technology are cited below.

"An official report on the Gagarin flight of 12 April 1962,  
states that the spaceship was built on the basis of  
experience obtained from the launchings of the first  
ship-satellites. [11] According to A. Shternfel'd,  
the structure of the Vostok was perfected during the  
previous launchings of Soviet ship-satellites. On  
the first, second, and third ship-satellites, systems  
were perfected and checked which assured the insertion  
of the ship into its orbit and the flight safety and  
control required for manned flight and recovery. Space  
physics was also investigated during the flight of these  
ships. On the fourth and fifth ship-satellites, the  
Vostok's structure and its systems for safe flight and  
recovery were further perfected. [21] The fourth  
and fifth ship-satellites, launched in March 1961,  
were considered final test shots for the Vostok.  
Each of these vehicles carried a dummy in the pilot's  
seat and an experimental dog (Chernushka in the fourth  
ship and Zvezdochka in the fifth) in the cabin." [11]

In an article written in connection with the Vostok-1 launching, Professor G. V. Petrovich states that in the four normal recoveries of the ship-satellites, the condition of the *cosmonauts' cabins* [analyst's italics] was such that it permitted their use for a repeat flight. The Vostok-1 was the sixth in the test series of ship-satellites. [22] This same idea is also expressed by another author. Discussing the Vostok-1 flight, Mar'yanin writes: "Vehicle recovery was checked repeatedly with ship-satellites. During these flights, test dogs Chernushka and Zvezdochka were landed safely in the ship." [23] According to reference 11, the same flight program was in effect for the ship-satellites and for the Vostok-1: "As a result of extensive and intense work, the spaceship Vostok was developed. In March of 1961, two final control launchings were conducted.... The flights were carried out according to the same program used for the first manned space flight." [11]

Using the official report on the Gagarin flight [11], H. Hoffman (GDR) states that the *Pravda* description of the Vostok-1 essentially holds true for the Vostok-2 [2]. The cosmonauts indicated that all the Vostok-type ships are alike. Popovich states: "All the Vostok-type ships are alike, except that the Vostok-3 and Vostok-4 were more comfortable and improved." [24]

The development of the Soviet carrier rocket is mentioned by Hoffman. He gives some data which usually are not published in Soviet sources. His comparison of the Soviet carrier-rocket systems with the U. S. systems makes it possible to determine approximately the method used for calculating the thrust values mentioned for Soviet carrier rockets. Discussing the orbital velocities of the Vostok spaceships, Hoffman states: "One can imagine what a powerful thrust was needed to accelerate the Vostoks I and II to such a high velocity and propel them over such long distances. The estimated thrust (based on information giving 20 million horsepower as the engine power expended) of the Soviet rockets was 750 to 1000 tons. This means that the launch weight of the carrier-rocket system was well over 500 tons and, therefore, corresponded approximately to the weight of three modern DZ locomotives with tenders. The power output of Soviet carrier-rocket systems is 25 to 30 times greater than that of corresponding U. S. systems.... The rocket tested in the Pacific Ocean on 14 September 1961 gives grounds to the conjecture that it was a carrier system capable of launching a 10-ton payload." [2]

## 2. General Configuration of Vostok-Type Spacehips.

In an article by A. Romanov and an official report, the Vostok spaceship is described in the following terms: "The Vostok spaceship consists of two basic units, one being the cosmonaut's cabin containing the inflight life support system and recovery system and the other, the instrument section. The latter section contains radio and telemetry equipment; the spaceship's retroengine assembly is also located in this section. The cosmonaut's cabin is quite roomy and the cosmonaut's seat is in its center. The catapult and pyrotechnic devices are built into its body alongwith parachute systems, emergency supplies of food, water, and equipment, and a radio set for communications and direction finding after landing.: [25] "The shell of the cabin has three portholes and two quick-opening hatches. The portholes are made of heat-resistant glass and permit visual observations to be made during the entire flight." [11]

Analysis of Soviet literature published over a period of several years leads to the conclusion that the Vostok spaceship is a winged vehicle and has a spherical cabin consisting of two hemispheres. This statement is discussed in detail in AID Report 61-101 [17]. This report shows the location of the pilot's seat in the cabin and the location of the quick-opening hatches mentioned above, one of which is used for ejection of the cosmonaut from the cabin.

The configuration of the Vostok-type spacehips is probably similar to that shown in Figure 9.

## 3. Reliability of Vostok-Type Spacehips.

Professor G. V. Petrovich says that it would be naive to suppose that the conquest of space will not claim any victims. For this reason the Vostok was equipped with systems for saving the cosmonaut in any emergency situation which could be foreseen on any part of the trajectory, starting with the moment before the launch and including the orbital flight and recovery. [22]

In an article commemorating the fifth anniversary of the launching of the first earth satellite, M. V. Keldysh describes the development of ship-satellites: "For the first time a method of returning a spaceship to earth was developed. This required special orientation systems..., the designing of

automatic braking devices for recovering the ship from orbit and landing it in a predetermined area. The scientists devised means of safeguarding the ship's hull from burning during passage through the dense layers of the atmosphere." [26]

Professor V. V. Dobronravov states: "Two methods may be employed in landing a spaceship: either a retroengine unit or velocity damping in the atmosphere. The first of these methods requires large fuel reserves. The second method does not have the above type drawback; however, it is not entirely reliable. The most effective [would be] a combination of these two methods." [12]

In an article on the Vostok-2 launching, K. Mikhaylov mentions the recovery-system redundancy and the probability of reliable operation of the systems in the Vostok spaceship, which he places at higher than 90%. He derives the reliability of the Vostok-1 as follows: "The automatic recovery system of the Vostok ship-satellite was backed up by manual control.... Besides this, the ship was inserted into such an orbit that if the manual system had failed, then over a period of less than ten days, the ship, influenced by air-resistance forces, would of itself gradually enter the dense layers of the atmosphere and descend.... If, for example, we would arbitrarily assume that the probable reliability of insertion into a given orbit [i.e. being in a correct orbit] is equal to 90% and the reliability of operation of the automatic and manual control systems is also 90% (for each), then, on the basis of the so-called 'multiplication theorem', the probability of failure will equal the product of the probability of failure for each of the recovery systems, i. e.,  $0.1 \times 0.1 \times 0.1 = 0.001$  or 0.1%. The operational reliability of all the components of Soviet rockets, which has been demonstrated by the many launchings, leads one to believe that the probability of reliable operation, stated as 90%, is a lower estimate." [27]

Petrovich further states: "The Vostok was the sixth in the test series of ship-satellites. All systems were tested and perfected in the previous flights, and stable results were obtained in the fourth and fifth shots." [22] Titov, in discussing the heat-shield reliability, states: "The heat shielding was reliable and had been checked many times in flight." [28]

Describing the orientation system of the Vostok-1, L. Mar'yanin says, "...everything was accomplished automatically by electronic computers which issued the necessary commands. However, we would not rest with this; a series of supplementary measures was developed in order to preclude the possibility of any accidents. The principal means was the manual flight-control system." [23]

From discussions by several authors, it follows that Vostok-type spaceships are equipped with wings. Discussing a method for recovering a cosmonaut during a landing back on earth, Yu. Marinin states: "Here, the cosmonaut will encounter the danger of landing far from the calculated area, in the mountains, or in swampland. In this event, in order to save the cosmonaut, the satellite should be equipped with means of controlling its flight, for example, wings." [29]

In a discussion of system redundancy, G. Titov states: "Our designers considered it necessary to duplicate and even triplicate the more essential systems and components, thereby considerably increasing the weight of the equipment.... Reserves of food, water, regeneration-system reagents, and electric power were included to sustain the cosmonaut for a period of 10 to 12 days, i. e., to make possible a safe descent through natural deceleration 5 to 12 days after launching." [30] This same idea is also expressed in passage by K. Kikhaylov quoted on p. 33. L. Mar'yanin supports this by saying, "Even though the first flight was of short duration, the food, water, and electric power reserves were wisely calculated to be sufficient for 10 days." [23] K. Gil'zin states: "Even if the absolutely reliable duplicate and triplicate systems of our spaceship malfunctioned, there would not be a catastrophe. The cosmonaut would safely descent to earth, because the orbit was so calculated that after 5 to 12 days of drifting in space, the ship-satellite would eventually decelerate in the atmosphere, descend, and make a landing." [30]

Ye. Grebenikov and V. Demin mention the cosmonaut's action in case of an emergency situation arising during the launching or recovery. They state: "If in the several seconds following liftoff a bright light flashes on the screen, he pulls a lever. The light indicates that a malfunction has occurred during the launch. The lever activates a catapult which ejects the capsule high into the air. A parachute automatically opens.... During descent, the cosmonaut again places his hand on the red lever." [31] According to H. Hoffman, a portable emergency kit is located in the pilot's seat: "The pilot's seat is equipped with...a portable emergency kit (food provisions, water, first-aid dressings), as well as with radio and direction-finding equipment which the cosmonaut might need after landing." [2]

According to some sources, the Vostok-type spaceships were suitable for repeated flights. G. V. Petrovich states that in the four normal recoveries of the spaceship-satellites "the condition of the cosmonauts' cabins was such that it permitted their use for a repeat flight after minor repairs to the outer covering only." [22] Speaking about the Vostok-4, Popovich states: "If I were permitted, I would fly with pleasure more than once in the Vostok-4." [24]

## SECTION C. DESCENT OF A SPACESHIP FROM ORBIT TO THE SENSIBLE ATMOSPHERE

### 1. Orientation System\*.

According to an official report, "the Vostok's orientation in space can be accomplished either by an automatic sun-seeking system or by the pilot. The former ensures proper turning of the ship and accuracy in maintaining the required position. The sensing units of the system consist of a number of optical and gyroscopic transducers. In manual control, the cosmonaut uses an optical orientation device for determining the position of the ship relative to the earth. The optical orientation device is mounted on one of the three cabin portholes and consists of two ring-shaped mirror reflectors, a light filter, and a glass with a grid. The sun's rays coming from the line of the horizon strike the first reflector, then pass through the porthole glass to the second reflector, which directs them through the glass with the grid to the cosmonaut's eye. When the ship is correctly oriented vertically, the cosmonaut sees an image of the horizon in the form of a circle and he observes the section of the earth's surface below through the center part of the porthole. The position of the longitudinal axis of the ship relative to the flight direction is determined by observation of the 'run' of the earth's surface in the vision field of the porthole. Using the control devices, the cosmonaut may turn the ship so that the line of the horizon is visible in the orientation device in the form of a concentric circle and the direction of the 'run' of the earth's surface coincides with the course line of the grid. This will indicate correct orientation of the ship. If necessary, the vision field of the orientation device may be covered with a light filter or a blind. A globe located on the instrument panel makes it possible to determine, along with the current location of the ship, its landing area if the retroengine is fired." [11]

Engineer N. Aleksandrov makes the following statements regarding the orientation and stabilization systems of space vehicles: "Soviet scientists and designers grappled successfully with this complex scientific and technical problem in 1959, with the launching of the interplanetary station to the Moon. Since that time not a single one of our spaceships has been launched without such equipment aboard...."

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\*)

In Russian, the term "orientation system" has essentially the same meaning as the American usage of the term "attitude control system."

"On the Vostok ships [orientation] is carried out automatically in relation to the sun and manually in relation to the earth. In both systems, the sensing elements are optical and gyroscopic transducers....

"In manual control, the cosmonaut can utilize the 'VZOR' optical system, a special control stick, angular-velocity transducers, and other devices. The optical orientation device is located on one of the cabin portholes. It is so constructed that when the ship is properly oriented, the cosmonaut sees an image of the horizon in the shape of a circle. The portion of the earth's surface located below [the ship] is visible in the central section of the porthole.

"The position of the longitudinal axis of the ship is determined by observations of the 'run' of the earth's surface in the vision field of the orientation device. If the direction of the 'run' coincides with the course line, it means that the ship is properly oriented. The appearance of deviations indicates the need to correct the ship's attitude. In this case the cosmonaut, [by] deflecting the control stick to the side required, sends command signals to the transducers of the orientation system. Signals from them are sent to the rocket engines -- to the thruster nozzles, from which a jet of gas is issued." [32]

In an article on spacecraft orientation and control, V. Vasil'yev and B. Semenov state that three flywheels with mutually perpendicular axes, powered by an electric motor, may be used to orient a spacecraft about its three axes. Flywheel weight can be reduced by increasing the speed of rotation; this, however, requires greater motor power and, consequently, greater weight of the power source. The optimum variant is that in which the overall weight is minimal. Discussing the orientation and control equipment aboard Vostok spacecraft, the authors state that a special optical device, the "VZOR," is used by the cosmonauts to observe the earth's surface and to orient the ship according to the local vertical and the direction of flight. Another method for determining the local vertical is through the use of a special device which detects the earth's thermal and infrared radiation. Automatic devices connect the orientation indicators to the spacecraft's orientation-control system. The authors describe the manual control system, stating that it is composed of control rocket engines, spacecraft rate-of-turn pickups, an optical orientation device, and other components. If the ship has deviated from a given position, the cosmonaut moves the control stick in the proper direction. With this, the rate-of-turn pickup receives a signal which switches on rocket engines. The craft begins to turn faster.

The rate of turn increases until it compares with that given by the cosmonaut. At this moment, the engines are switched off, and the craft rotates at a constant speed. As soon as the deviation has been corrected, the cosmonaut places the control stick in the neutral position. With this, the rate-of-turn pickup releases the signal given by the cosmonaut at the beginning of turning; i.e., it signals zero rate of turn. Instantly, rocket engines go into operation which begin to slow the ship. As soon as the rate-of-turn pickup signals that ship rotation has ceased, the engines are switched off. Therefore, each rotation of the ship about its center of gravity is accompanied by a twofold switching on of the rocket engines -- once for initiating rotation and once for stopping rotation. Discussing reentry, the article states that in order to accomplish reentry, the engine unit must produce thrust opposing the spaceship's direction of flight. For this, the craft must be turned so that at the moment of switch-on of the engine unit, the nozzles of the rocket engines face in the direction of flight. [33]

Analysis of several sources shows that the power unit of the orientation system consists of small nozzles and spherical compressed-gas tanks [34], which are located on the outer surface of the ship's instrument section [22]. Design Engineer I. A. Merkulov, describing the Vostok-3 and Vostok-4 flights, uses the word "engines" in relation to the attitude control system: "After separation from the rocket, only small engines for attitude control and a retroengine system assuring the ship's return to earth remain with the ship" [14].

"Additional details have been disclosed concerning the environmental control system of the Vostok spacecraft. Unlike the water-boiler arrangement in Mercury, which carried away heat by vaporization, the Soviet technique involves a heat exchanger in which the circulating coolant delivers the heat flux to the skin of the spacecraft, where it is radiated into space. Adjustable vents are used on the radiating portion of the spacecraft's skin to maintain the coolant at a constant temperature within the closed system. Cabin temperature is regulated by the quantity of air driven through the heat exchanger by the fan. The system has proved accurate to 1.5°C, according to the Soviet report.: [35]

The time lapse between switch-on of the Vostok-1's automatic orientation system and the completion of preparations of the onboard apparatus for switching on the retroengine was 24 minutes: "At 9:51, the automatic orientation system was switched on. After leaving the night side, the system performed a search for a orientation on the sun.... At 10:15, the commands came from the computer to ready the onboard apparatus for firing the retroengine." [11]

Describing her activity in the space during flight, Tereshkova writes that while in orbit she had to take over manual control and orient her spaceship. She switched on manual control, read and recorded the initial pressure in the tanks, and started timing with the stopwatch. The position of the earth in the porthole was such that it was advantageous to begin orientation about the pitch axis. She quickly oriented the ship in roll and yaw. She stopped the stopwatch, took readings of the instruments and recorded them. Tereshkova remarks that little time and "working medium" were expended and that the ship was responsive and easily controllable. According to her, a pitch maneuver followed by roll and yaw is literally called "orientation in the manner of landing." She states that in addition to carrying out this maneuver, she oriented the ship "in the manner of an airplane." [36]

## 2. "Space Compass" (Orbit Navigation Device).

Describing the command point at the cosmodrome, Mel'nikov states, "a device in the panel of which a globe is mounted has been set up in the room. The globe is an exact copy of that on the instrument panel of the Vostok-5. An engineer-designer explains that with this globe it is easy to determine the location of the cosmonaut at any given moment. It is possible to determine with this globe not only the location of the ship, but also its longitude, latitude, and the number of completed orbits." Cosmonaut Nikolavev was present during the engineer's explanation and commented: "It is an accurate device. I was convinced myself when I flew. You look into the porthole and see the yellow shape of Africa...and this device shows the same thing. In short, it is an excellent thing." [37]

In a discussion of the command point at the cosmodrome, Ostroumov refers to a navigational device used in the Vostoks: "In the communications room, a copy, or rather the twin, of the navigation device installed in the cabin of the Vostok-5 stands in an elevated position. A small, finely-detailed globe is set into its upper left-hand corner. On the spherical glass [shell surrounding the globe] there is a circle with a reticle. The globe is rotated at exactly the same angular velocity as the earth, and the oceans, continents, and islands drift beneath a point in the reticle. Now it is over the eastern part of the Indian Ocean; this means that the ship is there." Further description and a demonstration of the device by its designer indicate that there is another, smaller circle within the larger one; it is used during reentry and landing of the ship. To change the globe's setting from "orbit" to

"landing", a switch is thrown, causing the globe to skip to a new position. Here, a reticle on the small circle indicates the point at which the ship would land had the cosmonaut begun deceleration at that moment. Thus, the small circle helps the cosmonaut to choose the landing area. [38]

Peskov gives some additional information regarding the navigation device mentioned by Mel'nikov and Ostroumov. It is "...a silver box, two times smaller than an ordinary television set.... A small opening, like the speedometer of the 'Moskvich' automobile, shows the number of orbital passes." The designer of this device told Peskov, "Cosmonautics will develop further; there will be new carrier rockets and new spaceships. But this device, in all probability, will remain on board. It will never, it seems to me, become obsolete, any more than the compass became obsolete for travelers." [39]

In reference 40, the space compass is described as follows: "To determine the location of spaceships, in the cosmonaut's compartment there are three portholes, and on the instrument panel there is a small globe. This globe rotates continuously at a speed corresponding to the angular velocity of the earth's rotation and to the ship's motion in an orbital plane relative to the center of the earth.

"To get a graphic idea of how the cosmonaut determines the location of the ship in relation to the surface of our planet, let us put on the globe a circle inclined at an angle of  $65^\circ$  to the equator (approximately the same inclination angle as the Vostok-5 and Vostok-6). Let us attach the circle to the globe support and rotate the globe at a speed corresponding to the speed of rotation of the earth around its hypothetical axis. Along the orbit circle, at a continuous and definite angular velocity corresponding to the orbital velocity of the ship, let us set in motion a special indicator model of the ship. Observing the movement of the model on the globe, the cosmonaut determines the area of the earth over which he is flying." [40]

Ostroumov's article [38], appearing originally in *Izvestiya* was reprinted in a special booklet published by *Izvestiya* [41] that contains additional information on the space compass. Relating a conversation at the command point between reporters and the designer of the space compass, the author states, "We learned that the device, which in itself is a type of computer, requires a power of only 0.3 watts. In other words, it can operate on a flashlight battery.... This prime device in space navigation is the forerunner of all those which will appear in the future." [41]

In reference 42, Ostroumov stat. , "the descent of the Vostok-6 has begun. I picture how Tereshkova in her ship had switched her 'globe', how the tiny terrestrial globe had skipped over in the device, and how she watches the small circle designating the place [where she will] meet her friends." [42]

### 3. Retroengine Unit.

Discussing the use of engines for aerospace vehicles, in a 1959 article [43] N. Konovalov states, "Ramjets may be used in high-altitude, high-speed pilotless vehicles. In particular, they may be used for the interception of ballistic missiles. They may also be used for boosting space vehicles and for controlling their flight during recovery. Ramjets operating on nuclear fuel and ramjets using the energy of atomic oxygen found at high altitudes are now being developed." No indications were found showing that ramjets are used in the retroengine system of Vostok-type spaceships. L. Sedov, discussing the Vostok reentry, states, "Rocket engines were used for supplementary deceleration of the ship-satellite Vostok." [44]

Describing the reentry of Vostok-type spaceships, official reports and many Soviet writers use the general term "retro power unit," which does not indicate the number of retroengines for each spaceship. Most writers use the singular, and some the plural, of the Russian word for retroengine.

Figure 6 shows a typical reentry sequence for Vostok-type ships, as given by Soviet sources. Since the retro power unit is located in the rear of the spaceship, the spaceship is turned 180 degrees before the power unit is fired. Figure 6 and a diagram given in a TASS report [45] show the retro power unit with one jet; however, another TASS report [11] shows two jets. It is interesting to point out that East German author H. Hoffman, whose book is based on Soviet sources, including one of the above TASS reports [11], gives a reentry diagram which differs from that shown in Figure 6 and other Soviet sources. According to Hoffman (Figs. 4 and 7), the retro power unit is located in the forebody of the spaceship, which need not be turned 180 degrees before the firing of the power unit.

The plural of the Russian word for retroengine is given in several sources, including an article by military reporters S. Kovalev and others: "At a predetermined time, the solar

orientation system accomplished its operation cycle. After some time, the retroengines [of the Vostok-1] cut in." [46] The singular of the work for retroengine is used by Titov in a TASS report, where he refers to the Glenn effect as the problem of "fireflies" or the "phenomenon of small luminous dots floating past the porthole of the spaceship.: Titov says, "I also saw these luminous dots during the flight, and explained their origin thus: During scavenging (cleaning the engine), burnt gases and liquids under conditions of weightlessness turn into drops, scatter, and luminesce in the sun's rays. During Glenn's flight, this could also have been drops of moisture thrown off by the so-called evaporator -- the device which controls humidity and temperature in the cabin. Glenn, it is true, does not quite agree with my point of view. I think that this debate is immaterial. However, let's fly some more, and we shall see." [47]

During his historic flight, cosmonaut V. Bykovskiy made the following notations in his log. He stated that the g-forces and the imperceptible ignition of the last stage. During their flights, Titov, Nikolayev, and Popovich observed small white particles following their ships. Bykovskiy wrote the following concerning this phenomenon: "...when the ship leaves the night side and the light comes from my left, I can see luminous dots out the right porthole moving at a distance of 20 to 30 cm and up to 2 meters from the ship. Their movement appears as if they are leaving the ship or the ship is passing by them. I have observed this phenomenon each time I leave the night side..." V. Tereshkova wrote the following concerning this phenomenon: "Out of the right porthole at sunrise, I observed a mass of small particles. [It is] as if I am passing through a meteor layer." Bykovskiy, who floated about his cabin for one entire orbit, noted that there was plenty of room and if [suit] ventilation were provided during free floating, it would be possible to remain in the floating state for any amount of time. He further noted that during free floating, the angle of vision outside the porthole is greatly increased, but it is very difficult to determine relative distances. When the lights are out, orientation is difficult; there is neither a floor nor a ceiling. [19]

Some indications of the weight and power of the retroengine unit for Vostok-type spaceships are given by I. A. Merkulov when he discusses the transfer of a spaceship from an earth orbit to a descent trajectory: "For example, to change the speed of a spaceship by 100 m/sec, it is necessary to have a power unit which comprises from 3 to 6% of the ship's weight [cabin, payload, cosmonauts].

"To change the speed by 2 km/sec, it is necessary to have a fuel supply equal to 40 to 60% of the ship's weight. The weight of the entire unit for maneuverability comprises 50 to 80% of the ship's weight....

"To transfer a spaceship from an earth orbit to a descent trajectory requires a very small change in its speed. For instance, for orbiting ships flying at altitudes attained by the Vostok-3 and Vostok-4, it is sufficient to decrease the speed by 40 m/sec for them to descend below 100 km and, having entered the dense layers of the atmosphere, to decelerate quickly and land on the earth's surface. Such a change in speed requires a very small power unit, comprising only 1 to 2% of the ship's weight." [14]

Several sources contain statements to the effect that brief, intermittent operation of the retroengine is more advantageous than prolonged, continuous operation. Merkulov gives the following opinion relative to engine operation for maneuvering: "The weight of the power unit is not dependent upon whether the speed of the spaceship is changed by a given value immediately through prolonged, continuous engine operation, or by brief, intermittent operation with each ignition giving a relatively small increase in speed. The weight of the power unit is dependent upon the total increase in speed, regardless of the number of firings and duration of operation." [14]

It is interesting to note that in describing the Soviet reentry system, various authors use the words "retroengine unit," "retro power unit," "retroengines," or "regroengine." However, K. Gil'zin, in describing the American reentry system, uses the word "retrorocket." He states, "Fuel is also necessary for retrorocket operation, i.e., rockets for decelerating the ship and for transferring it to a descent trajectory." [30] This difference in terminology probably reflects the difference between the retro power units used for Vostok-type spacecraft and those on Mercury vehicles.

#### 4. Deceleration by Retro Power Unit and Free Descent of a Spaceship Along the Reentry Trajectory.

Relative to the deceleration of space vehicles, I. A. Merulov states the following: "Research has shown that for circumterrestrial flight, the best altitudes are from 160 to 400 km....

"At an altitude of 100 km, a 10-ton craft travelling at orbital velocity will not complete even one orbit, since the ship's speed decreases by 51 m/sec during one orbit.... At 200 km,...the ship's speed will decrease by only 0.05 m/sec, and the altitude will decrease by 0.2 km in one orbit.... If at an altitude of 180 km a rocket inserts a ship into orbit with a speed only 0.5% less than orbital velocity, the ship will not complete the orbit, but will enter the dense layers of the atmosphere and terminate its flight.... To lift a ship travelling at 7791 m/sec from a circular orbit at 200 km to an altitude of 300 km requires increasing the flight speed by 29 m/sec." [14]

From a TASS report on the Vostok-1 flight it is evident that the ship moves at a constant speed along the descent trajectory from the retroengine cutoff point to the dense layers of the atmosphere: "At a predetermined point in the orbit, the retroengine unit is fired; this provides a decrease in the ship's speed to the required calculated value. As a result, the ship transfers to a descent trajectory. The cabin containing the cosmonaut decelerates in the atmosphere." [11]

In a description of the Vostok-3 and Vostok-4 flights, P. Vasil'yev makes the following statements: Prior to deceleration, the spaceship was travelling in its orbit at a speed of 30,000 km/hr...."

"The retroengine reduces the speed a little...."

"The spaceship approaches the dense layers of the atmosphere at a speed of about 28,000 km/hr." [48]

In an article written in connection with the Vostok-3 and Vostok-4 flights, N. Ushakov states: "The retroengines are cut off. The spaceship leaves the circular orbit and starts to descent. At a speed of approximately Mach 25, it penetrates into atmosphere of ever-increasing density." [49]

From a source published in East Germany [2], it follows that the maximum orbital velocity of the Vostok-1 and Vostok-2 spaceships was about 28,800 km/hr. The same orbital velocity for Vostok-1 is also mentioned by A. Il'yushin when he discusses the reentry of this vehicle. According to him, "the Vostok-1 flew at an orbital velocity of almost 8 km/sec. If a satellite is suddenly stopped, it will fall to earth vertically.... Another method might be used: the retro power unit decreases the speed, for instance, to 6 or 7 km/sec. Then the cosmonaut descends along a trajectory close to parabolic. This apparently was the case with the Soviet cosmonaut." [50] It should be

mentioned that Il'yushin is the only author quoted in this report who thinks that the Vostok-1 descended along a parabolic trajectory and that the vehicle's orbital velocity was decreased by a value of 1 to 2 km/sec. According to several other sources, the Vostok-1 descended along an elliptic trajectory, and its orbital velocity was decreased by a small value. In describing his flight, Gagarin states, "The retroengine unit worked perfectly. The Vostok gradually began to lose speed and went from its orbit into a transfer ellips.: [51] From reference [2], it follows that deceleration during the operation of the retroengine unit was relatively small and Gagarin tolerated it easily.

As is shown above (Section B, 1.), all the Soviet Vostok-type spaceships were launched according to the same program. Therefore, the following information concerning the fourth ship-satellite flight might also be related to the Soviet manned flights. Describing the flight of the fourth ship-satellite carrying the dog Chernushka, A. Shternfel'd states that the deceleration of the ship by the atmosphere begins at an altitude of 90 km and that the retroengine decreases the orbital velocity by a value of less than 50 m/sec. Shternfel'd states: "Calculation shows that the ship-satellite travelled at a speed of 7831 m/sec in perigee. As the ship moved away from the earth, its speed decreased in apogee to 7753 m/sec.... We assume that deceleration by the atmosphere begins at an altitude of 90 km. Calculations show an interesting fact: If for descent from perigee a ship-satellite should have a velocity of 7783 m/sec relative to the earth's surface, then, for descent from apogee, 7726 m/sec is sufficient. Therefore, in order to initiate descent from the farthest point in the orbit, the velocity must be decreased by 27 m/sec, while from perigee, it must be decreased by 48 m/sec. Hence it is apparent that the savings in velocity, and consequently fuel, would consist of a little more than 40 percent.

"We wish to note that this in no way means that the command for the descent of the fourth ship-satellite was given precisely at the moment of its passage through the apogee. Actually, fuel economy is far from always being the deciding factor.... Nonetheless, the described method of descent from apogee has theoretical interest. For highly elongated orbits where the altitude in apogee exceeds that in perigee by several times, the use of this type of descent permits a great saving in fuel, and, as a consequence, rockets with less power can be used to launch artificial satellites. For instance, for an artificial satellite completing a flight around the moon and the earth (with a lower perigee), descent from apogee would yield a tenfold saving in fuel." [52]

Discussing the Vostok-1 flight, a TASS report states: "From the moment that the retroengines were fired prior to landing, the ship travelled about 8000 km. Flight time for the descent phase was about 30 minutes.... At 10:15, the commands came from the computer to ready the onboard apparatus for firing the retroengine.... At 10:20, the retroengine was fired and the ship went from the orbit of an earth satellite to a descent trajectory. At 10:35, the ship began to enter the dense layers of the atmosphere." [11] Another TASS report gives the following figures for the Vostok-3 and Vostok-4: "At 9:24 Moscow time on 15 August 1962, the retroengine unit was switched on aboard the Vostok-3; six minutes later [it was switched on] aboard the Vostok-4, after which, both ships [sic] began their descent." [53]

Analysis of reference 13 shows that the instrument section of the spaceship separates from the cabin section somewhere along the reentry trajectory at the end of the high-temperature and overload zone.

Discussing the Gagarin flight, O. Kudenko states, "Yuriy knows that located behind his back are complex instrumentation systems. They control the operation of all the ship's mechanisms. The final commands are transmitted from earth. Now, the instrument section must be jettisoned. For a moment, he [Gagarin] feels sorry for these 'intelligent' instruments. Afterwards, on the duralumin rings of the portholes, through the protective shutters, he sees the blood-red reflection of the red-hot coating of the ship's body.... The temperature on the ship's surface is many thousands of degrees.

"The ship shakes as it penetrates into the sensible atmosphere. The overloads increase, and the deceleration units roar. The pilot's voice sounds gay and calm as before: 'The cabin temperature is 20 degrees. I can feel the overloads. Everything goes well. The instrument section has been jettisoned'." [13]

## SECTION D. DESCENT OF A SPACESHIP THROUGH THE SENSIBLE ATMOSPHERE

### 1. High Temperature and Overload Phase.

The recovery phase of a space mission is considered by Soviet authors as more difficult than the launching: "According to reports by Gagarin and Titov, the moment of reentry, when the spaceship enters the dense layers of the atmosphere and rapidly approaches the earth, is no less difficult than the launching." [54] In an article by N. Kamanin, G. Titov, and others, the authors state: "The most difficult and important stage of a space flight is the recovery. One need not even speak of what a test of will and self-control it is for a ship to enter the dense layers of the atmosphere. When hot tongues of fire burst astern and the terrible weight of overloads descends upon his shoulders, not only physical stamina is required of a cosmonaut, but also moral." [55] The high temperature and overload phase mentioned in reference 55 is also discussed in general terms by A. Yurok. Describing the Gagarin flight, Yurok states: "During descent, the cosmonaut again places his hand on the red lever. Negative g-forces descend heavily upon his body. However, the cosmonaut is capable of taking over from the automatic controls at any moment. Everything goes well and the automatic system has released the ribbon parachute; the g-force have increased sharply. Now the main canopy has opened; the dense layers of the atmosphere have been entered. It is hard on the pilot. The g-forces decrease slowly. The pilot is beyond even thinking of looking out of the porthole." [70]

The overloads during reentry are considerably greater than during launching. For Gagarin's flight, "...the acceleration overloads reached 6 to 8 g's, while the maximum value for deceleration overloads was about 10 g's.... This maximum overload appeared at an altitude of about 50 km... The vehicle entered the sensible atmosphere at a speed of 8 km/sec.... The period of high overloads for the Vostok-1 lasted about 15 minutes." [2] A TASS report states: "At 10:35, the ship began to enter the dense layers of the atmosphere.... At 10:55, the Vostok-1 landed in the predetermined area." [11] Thus the time between the Vostok-1 entry into the sensible atmosphere and its landing was 20 minutes. This period of time is mentioned also for another vehicle, a satellite container using a metal parachute: "The container will float down from the satellite to Earth in 20 minutes." [56] Professor G. I. Pokrovskiy, in a general discussion of the high-speed motion of a body, states: "Usually, movement at high speed through the atmosphere is not continuous. For example, if even a comparatively slight deceleration occurs,

in which the decelerating force is equal to the weight of the body, then for a reduction in speed from orbital velocity to zero, 800 seconds (about 13 minutes) are required." [57]

In discussing high-altitude aerodynamic drag, two references state the following: "At altitudes above 200 km, the heating of a flying body due to drag is very small and can be compared with the heating produced by the radiant energy of the sun and the earth." [58] "Noticeable deceleration of a satellite begins at an altitude of 200 km." [59] From an article by A. Shternfel'd, it follows that during the reentry of a spaceship, significant aerodynamic deceleration begins at an altitude of 90 km. [21]

## 2. Characteristics of a Shock-Wave Front.

This section contains material showing conditions surrounding the reentry of space vehicles and principles relating to the calculation of shock-wave fronts. The material given below consists entirely of statements translated from Russian, arranged by subject matter and listed under author and reference number:

### Pokrovskiy, G. I., Professor, 57:

"There are two types of interaction of bodies with a medium: interaction of individual molecules and interaction with a continuous medium. As a conditional boundary between the types of interaction, we can use that density of the medium present when the length of the free path of a molecule is equal to the diameter of the moving body. For a body with a diameter of one meter, this boundary in the atmosphere can be found at about 116 km. For a body having a diameter of 10 meters, this altitude increases to 133 km.... The length of the free path at an altitude of 50 km is equal to 0.01 cm; at 100 km, it is 10 cm, and at an altitude of 150 km, it reaches 100 meters.

### Merkulov, I. A., Engineer, 14:

"If a body flies at subsonic speed, air particles a short distance ahead of the body receive a signal in the form of a sound wave. The particles give way and flow around the sides of the body.... However, a completely different picture is presented when a rocket or other body moves in the atmosphere at speeds exceeding the speed of sound. In this case, the vibrations of the air particles, occurring as a result of the body's motion, literally speaking, are unable to 'inform' the air particles ahead of the approach of the body. Without receiving the wave 'signal', the air particles are not able to give way.

Then follows an impact of the body with stationary air. A region of highly compressed gas forms in front of the body."

Petukhov, B. S., Doctor of Technical Sciences, 60:

"Thermal dissociation of molecules takes place in the flow (or boundary layer) at a temperature above  $2500^{\circ}\text{K}$ , and the atoms recombine in the cold parts of the boundary layer.... Ionized gas is formed under very high temperature conditions — about  $10,000^{\circ}\text{K}$ .... If the speed of the body (or gas) is no higher than about Mach 6, the effect on heat transfer of the compressibility of the gas and the variation of its physical parameters with temperature is taken into consideration together with drag [in calculating the boundary layer].... At speeds of about Mach 10 and higher, it is necessary to consider not only the compressibility and physical parameters of the gas, but also the effect of dissociation and recombination and the catalytic action of the wall."

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"In shock waves, air stagnation bears a shock character and the increase in temperature, characterized by a change in speed or pressure as air passes through the wave, is dependent on the intensity of the wave. Thanks to the shapes of modern aircraft, the intensity of the wave is not great. Consequently, the heating of air behind the wave does not, in practice, influence the heating of the aircraft. The greatest influence on the surface heating aircraft is provided by flow stagnation in the boundary layer."

Mikoyan, A. I., Chief Designer, 62:

"Flight at speeds corresponding to Mach numbers of about 6 and 8, i.e., the beginning of the hypersonic range, in essence does not change the laws of supersonic aerodynamics, even though it may require a change in the external form of aircraft. By increasing the flight speed to Mach 10-15, we meet several new phenomena. For instance, in air, chemical processes are initiated which are related to the dissociation of air.

"The disintegration of air molecules with the liberation of atomic oxygen, and later nitrogen, leads to their interaction with the result that nitric oxide begins to form and the chemical composition of the air is changed. Further increase in hypersonic velocities will be connected with the occurrence of atom ionization processes, since, when atoms collide, they lose electrons and become charged particles...."

Pokrovskiy, G. I., Professor, 57:

"Gas heated to a high temperature and highly ionized is termed plasma. With movement at a velocity exceeding 3 to 4 km/sec, air flowing around a moving body turns into air plasma. In plasma, the basic energy carriers are electrons."

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"The layer in which a change occurs in the velocity of flow from zero to flight velocity is termed the boundary layer.... The boundary layer is called laminar if the currents of air in it move parallel to each other.... At high flight speeds, heat transfer from a laminar layer to the surface of an aircraft is many times less than the heat transfer from a turbulent layer, when all other conditions are equal."

Mikoyan, A. I., Chief Designer, 62:

"By maintaining a dynamic head of about 5000 kg/m<sup>2</sup>, it is possible to attain flight speeds of 18,000 km/hr at an altitude of 40 km; this is 15 times faster than the speed of sound at the same altitude. Air density at an altitude of 40 km, compared with the density at 20 km, is 20 times less; the atmosphere is so rarefied that the length of the free path of molecule of air increases to perceptible dimensions and is about 0.02 mm, while at the same time on earth, the length does not exceed 0.06 microns."

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"Stagnation temperature can be calculated approximately by the formula

$$T_{\text{stag}} = T + 5\left(\frac{V}{100}\right)^2 \quad [^{\circ}\text{K}],$$

where  $T_{\text{stag}}$  is the stagnation temperature,  $T$  is the air temperature in front of the shock wave, and  $V$  is the flight speed. The first Soviet satellite entered the atmosphere at a speed of 8000 m/sec. The air stagnated by the artificial satellite heated up to 32,000°C, since

$$T_{\text{stag}} - T = 32,000^{\circ}\text{C}."$$

Pokrovskiy, G. I., Professor, 57:

"Behind a shock wave, air density increases sharply, and the direction of motion of the air stream changes significantly; besides this, the air temperature increases greatly. For orbital velocity at an altitude of hundreds of kilometers, the stagnation

temperature is equal to about  $3160^{\circ}\text{K}$ . At the escape velocity necessary for a moving body to escape the limits of the earth's gravitation, the stagnation temperature reaches  $60,000^{\circ}\text{K}$ . These stagnation temperatures, which characterize heated air-flowing around a body, occur only at a point near the forward portion of the body and not throughout the entire air mass. For all other portions [of the body], the air temperature is lower."

Mikoyan, A. I., Chief Designer, 62:

"Initially, the stagnation temperature of air flowing about an aircraft at high supersonic velocities increases almost quadratically with an increase in the Mach number. Therefore, at a flight speed of 2000 km/hr, the stagnation temperature is approximately  $100^{\circ}\text{C}$ ; at about 5000 km/hr, the stagnation temperature will be 1000 to  $1100^{\circ}\text{C}$  and at 10,000 km/hr,  $3500^{\circ}\text{C}$ ."

Perel'man, R. G., Candidate of Technical Sciences, 63:

"At an altitude of 11 km, the density of air is three times lower than at the surface of the earth and the temperature is about  $-50^{\circ}$ .... At a speed of Mach 1, the temperature of the air is  $+50^{\circ}$ , and at a speed exceeding 2000 km/hr, the temperature is  $+200^{\circ}$ .... When a speed of 4500 km/hr is attained, the skin of the nose section and leading edges of the wings are heated to a glowing red; a thermometer located on the skin of the aircraft reads  $500^{\circ}$ .... At Mach 5, the aircraft becomes red hot, the thermometer reads above  $600^{\circ}$ ...."

Merkulov I. A., Engineer, 14:

"When a bullet, a supersonic airplane, or an artillery shell travels at a speed two times greater than the speed of sound, the air temperature in front [of the object] increases to  $240^{\circ}$ . When the flight speed increases to three times the speed of sound, the temperature rises to  $500^{\circ}$ . In front of a rocket travelling at a speed of 2.5 km/sec, the air temperature reaches  $2500^{\circ}$ ."

Perel'man, R. G., Candidate of Technical Sciences, 63:

"The transfer of energy from oncoming air to the surface of a moving body occurs at temperatures up to  $3000-4000^{\circ}$  basically as a result of molecular bombardment....

"If the stagnation temperature exceeds 3000 to  $4000^{\circ}$ , which corresponds to a velocity exceeding 4500 to 8000 m/sec, marked ionization of the air begins. In ionization many free electrons appear. In a highly heated gas, electrons move one hundred times faster than atoms and molecules."

L'vov, V., Engineer, 58:

"According to calculations, at Mach 10 the temperature of the air on the surface of a flying body is about 5000 to 6000°C."

Votyakov, V., and B. Shumyatskiy, 64:

"The thermal boundary layer near an airplane flying at an altitude of 30 km at a speed of  $M = 2.7$  will heat up to a temperature of 290°. For a rocket having a speed of  $M = 10.7$ , this temperature will reach 3150°. The boundary layer of an intercontinental ballistic rocket ( $M = 21.3$ ) may heat up to almost 7000°."

Sushkov, Yu., Engineer, 59:

"An 'air cushion' formed by compressed gas appears between the shock wave and the satellite. The temperature of the compressed gas is 4000 to 8000°C."

Kudenko, O., 13:

"The Vostok slowly enters the upper layers of the atmosphere. It vibrates as it overcomes the dense layer of air. Its skin heats up. Yuriy looks at the thermometer. On the ship's surface the temperature reads 2000, then 3000, then 5000°C. The temperature rises rapidly."

Mikoyan, A. I., Chief Designer, 62:

"Supersonic aircraft of ordinary design with a wing loading of 300 kg/cm<sup>2</sup> to 400 kg/cm<sup>2</sup> at an altitude of 20 km have a minimum flying speed approximately equal to the speed of sound; at an altitude of 40 km, this speed is five times greater."

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"In a flow about the surface of an aircraft, the heating of the air in the boundary layer increases the temperature of the surface itself. If the flow does not decelerate or, conversely, accelerates due to expansion, then its temperature decreases, since in order to accelerate it is necessary to expend a certain amount of internal energy; i.e., thermal energy is transformed into kinetic energy."

"Calculation indicates that if the temperature of air at rest is equal to +15°C, then an increase in its velocity (obtainable through a drop in pressure) leads to a decrease in temperature to -45°C at a velocity corresponding to  $M = 1$ . For a flow velocity corresponding to  $M = 2$ , the air temperature decreases to -121°C, while at  $M = 3$ , it drops to -175°C."

L'vov, V., Engineer, 58:

"Theoretically, the surface temperature of a body flying with a velocity of Mach 10 will be about 5000 to 6000°...."

Pokrovskiy, G. I., Professor, 57:

"Temperature characterizes the energy of the unordered motion of molecules. Energy and temperature are proportional to the square of the mean velocity of the motion. Therefore, if the velocity of the molecules of a body increases by four times, then its temperature increases by 16 times."

Sushkov, Yu., Engineer, 59:

"In the dense layers of the atmosphere a satellite flies under conditions of hypersonic flight. Under these conditions, sound waves cannot overtake the flying body, and thus compressed gas appears between the shock wave and the satellite."

Pokrovskiy, G. I., Professor, 57:

"We shall assume that a rocket with a cross sectional area of 10 m and a forebody in the form of a hemisphere moves at orbital velocity near the earth. Under these conditions, aerodynamic calculation shows the force of air resistance is 500,000 tons. Ten meters away from the rocket, pressure in the ballistic wave reaches 22 atmosphere, which corresponds to a loading of 220 ton/m<sup>2</sup>. Even at a distance of 10 kilometers from the rocket, the loading from the ballistic wave will equal 220 kg/m<sup>2</sup>.... During condensation of water, energy is released.... The formation of contrails can accompany the release of energy which is two to three times greater than the energy of the engines. Correspondingly, there is an increase in the energy given off by a ballistic wave, and the wave pressure increases by 1.5 to 2 times."

Perelman, R. G. Candidate of Technical Sciences, 63:

"At an altitude of 11 km and a speed of 3000 km/hr, 160 horsepower for every square meter of surface area is required to compensate for air friction."

Malyutin, K., Engineer, 3:

"The [kinetic] energy of a 5-ton Vostok-type spaceship prior to reentry into the atmosphere is colossal; it is equivalent to the [kinetic] energy of 400 to 500 freight cars moving at a speed of 70 km/hr."

### 3. Heating of Aerospace-Vehicle Surfaces.

This section contains material relating to heat flow in aerospace vehicles. The material given below has been translated from Soviet sources and is listed under author and reference number.

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"The amount of heat which must be given off per square meter of surface by an aircraft flying at 15,000 meters at a speed corresponding to mach 4 is very high and is equivalent to 200 kilowatts."

L'vov, V., Engineer, 58:

"The heat flow which heats the skin of an aircraft depends on the altitude. At a speed of Mach 2.5 and at an altitude of 10 km, the heat flow is one third that at sea level; at an altitude of 18 km, it is one tenth that at sea level."

Votyakov, V., and B. Shumyatskiy, 64:

"The radiative ability of bodies depends on their temperature. Therefore, if the skin temperature rises from 20° to 315°C, then the heat flow from its surface to the atmosphere increases 16 times. The boundary layer does not hold this flow, since air possesses the property of being 'transparent' to heat rays."

Zhovinskiy, N. Ye., Candidate of Technical Sciences, 61:

"The maximum temperature of an insulated wall (surface) of an aircraft can be determined by the formula

$$T_c = T_0(1 + 0.2 rM_1^2) [^\circ\text{K}],$$

where  $T_c$  is the air temperature in the boundary layer near a heat-insulated wall in the absence of heat radiation, or the wall temperature;  $T_0$  is the temperature of the flow on the outer limits of the boundary layer;  $M_1$  is the local Mach number; and  $r$  is the temperature recovery coefficient.

"The temperature recovery coefficient  $r$  is the ratio of the actual air temperature increase near the heat-insulated wall (in the absence of heat radiation) to the theoretically possible increase during stagnation, taken without consideration of heat transfer or the internal friction of particles in the boundary layer; this ratio is expressed as follows:

$$r = \frac{T_c - T_0}{T_{\text{stag}} - T_0}$$

where  $T_{stag}$  is the stagnation temperature of the air.

"Experimental and theoretical investigations have shown that  $r = 0.9$  for a turbulent boundary and  $r = 0.85$  for a laminar layer; therefore, the maximum value for the temperature of the inner side of the skin of an aircraft for a turbulent boundary layer is  $T_c = T_0 (1 + 0.18 M_1^2)$  [ $^{\circ}K$ ]; for a laminar boundary layer, it is  $T_c = T_0 (1 + 0.17 M_1^2)$  [ $^{\circ}K$ ]. At altitudes exceeding 11 km, the temperature of the surrounding air is equal to  $-56^{\circ}C$  and the flight speed is equal to the local Mach number. Under these conditions, when  $M = 2$ , the air stagnation temperature is approximately equal to  $+117^{\circ}C$ . The maximum skin temperature of an aircraft when the boundary layer is turbulent is about  $+101^{\circ}C$ , while for a laminar boundary layer the skin temperature is about  $+92^{\circ}C$ ."

Ponomarev, A. N., Lieutenant General, Technical and Engineering Service, 15:

"During flight at high altitudes and at speeds of about 2500 km/hr, the temperature of the aircraft's surface reaches  $200^{\circ}C$ ; at speeds of about 3000 km/hr, the surface temperature is close to  $300^{\circ}C$ ."

Malyutin, K., Engineer, 3:

"At an altitude of 10 km, the heat fluxes acting on the skin of an aircraft flying at Mach 2.5 are three times less than at the surface of the earth, while at 18 km, they are ten times less. At an altitude exceeding 200 km, the heating of the craft is so small that it can be compared with radiant energy received from the sun and the earth.

"The outer shell of a spaceship, particularly its pointed forebody, is subjected to gas-kinetic heating during reentry into the atmosphere. The shell temperature can exceed  $1000^{\circ}$ ."

Danilin, B., Candidate of Technical Sciences, 65:

"At a speed of 1.5 km/sec, the nose will become heated to a temperature over  $1000^{\circ}C$ ."

Borisov, V., 66:

"Upon entering the dense layers of the atmosphere, the ship-satellite decelerates due to friction with the air; its energy reserve is spent on heating the air and the heat-shielding layer of the ship. On the assumption that only 0.01 of the kinetic energy is expended on heating the ship-satellite, then the

remaining 0.99 [is expended] on heating the air; therefore, in these circumstances, the ship-satellite heats up to a temperature of 1000°."

#### 4. Cosmonauts' Impressions of Reentry.

Discussing the motion of the Vostok-1 along the reentry trajectory, O. Kudenko states: "Now, the instrument section must be jettisoned.... Afterwards, on the duralumin rings of the portholes, through the protective shutters, he [Gagarin] sees the flame and the blood-red reflection of the red-hot coating of the [ship's] body. The skin temperature of the ship is many thousands of degrees. The ship shudders as it passes through the dense layers of the atmosphere. The overloads increase, and the brake installations roar. However, the pilot's voice, as before, sounds cheerful and calm: 'Temperature -20°C. Experiencing overloads. Instruments section jettisoned.'"

Gagarin states: "The ship began to enter the dense layers of the atmosphere; its outer shell rapidly became red hot, and through the shutters covering the porthole I saw an awe-inspiring crimson glow from a flame billowing around the ship. The overloads increased; they were more noticeable than during takeoff." [51] After his landing, Gagarin recalled his flight and stated: "...and before one's eyes, there is the turbulent red reflection of the burning coating." [67]

Soviet cosmonauts do not mention the overloads experienced during the firing of the retroengines. Describing the recovery, they mention the effects of overloads experienced during the reentry into the dense layers of the atmosphere. Titov states: "The system for orienting the ship worked with exceptional accuracy. Then the retroengine fired.... The Vostok-2 left its orbit and began to approach the dense layers of the atmosphere. Weightlessness somehow ceased of itself.... The Vostok-2 entered the dense layers of the atmosphere; its heat-protective shell quickly became red hot, causing a bright glow in the air flowing past the ship. I did not close the shutters on the portholes; I wanted to follow closely what was going on outside. The light pink color surrounding the ship intensified to blood red, purple, and finally deep purple. I squinted at the boiling fire, consisting of the brightest of colors. The heatproof glass of the portholes turned yellow, but I knew that there was no cause for alarm; the ship's heat shielding was reliable and had been checked many times in flight.

"Weightlessness had completely ceased. The reentry overloads pressed me against the seat with enormous force.... Soon,

the overloads completely ceased, and the glowing air outside the ship vanished. All the systems worked perfectly. The ship went precisely to the predetermined landing area." [28] In another article Titov states: "Hot tongues of fire burst astern." [55]

Describing the movement of the Vostok-2 through the dense layers of the atmosphere, Titov and the authors of reference 68 state: "It seemed that the ship had flown into a volcanic crater and was passing not through the atmosphere but through the hard earth itself.... Yellowish-crimson droplets flew past the astonished gaze of the cosmonaut." [68]

#### 5. Aerodynamic Methods for Decelerating Space Vehicles in the Sensible Atmosphere.

In a discussion of transport rockets, G. Pokrovskiy states: "The load may be landed by opening the metal tail unit, firing the retroengine, and [deploying] parachutes." [69]

From Hoffman's book, it follows that during reentry of Vostok-1 and Vostok-2, aerodynamic brake flaps, steel-strip parachutes, and conventional parachutes were used. Discussing the most difficult reentry period, which lasted about 15 minutes, the author states: "Aerodynamic brake flaps [aerodynamische Bremsklappen], extended from the sides of the space vehicle, improved the atmospheric deceleration.... The final phase in the spaceship's return to earth undamaged at a landing speed of only 5 m/sec." [2]

Discussing the reentry of a satellite in 1958, M. V. Vasil'yev states: "When the operation of the retroengine is completed, a metal parachute opens above the container." [56]

In an article on the Gagarin flight, A. Yurok discusses the reentry in the following terms: "Everything goes well, and the automatic system has released the ribbon parachute; the g-forces have increased sharply. Now the main canopy has opened; the dense layers of the atmosphere have been entered." [70]

A regulating "skirt" is shown and mentioned in an article by V. Votyakov and B. Shumyatskiy, on the flight of a ballistic missile: "According to the authors, the greater portion of the path of a ballistic rocket passes through the upper layers of the atmosphere. In order to regulate the speed of the rocket's entry into the atmosphere, a regulating 'skirt' is sometimes attached to the afterbody. As air density increases, the width of the 'skirt' changes, as a result of which the frontal drag of the rocket changes." [64] The regulating "skirt" shown in reference 64 is similar to that in Fig. 11.

A TASS report on the Vostok-2 flight states: "At a given point along the orbit, after the retrosystem cuts off, the ship descends from orbit onto a descent trajectory. After passing through the zones of high temperatures and g-forces, the landing system, assuring the ship's low-speed touchdown, cuts in not far from the surface of the earth." [71]

The recovery system of the Vostok-3 and Vostok-4 are also mentioned in a TASS report, where the following is stated: "At a fairly low altitude, when the ships had already passed through the region of high temperatures and overloads, the cosmonauts egressed from the ships in ejection seats and opened their parachutes. The ships, without the cosmonauts, continued to descend and landed safely, thanks to the automatic system." [53]

According to the cosmonauts, the Vostok-1 vibrated during reentry, and the Vostok-2 spun. Gagarin states: "The Vostok slowly enters the upper layers of the atmosphere. It vibrates as it overcomes the dense layer of air." [13] According to Titov, "When I entered the dense atmosphere, the real impact of overloads hit me, and in addition, [the ship] began to spin [about its axis]." [68]

Yu. Sushkov states that a parachute will be damaged by the air flow at altitudes below 50-60 km, and at an altitude of 80-90 km, the parachute cannot open by itself. He observes that Soviet meteorological rocket flights showed that during recovery of the containers from an altitude of 80-90 km the parachute did not open by itself initially; it only served to direct the container. [59] Another source writes that the parachute started to open at an altitude of 60 km. [77] The use of a parachute for the deceleration of a satellite is not satisfactory, since "tens of revolutions" are needed to reduce its speed to the required values. [59]

## SECTION E. PROTECTION OF AEROSPACE VEHICLES FROM OVERHEATING

### 1. Materials Used for Aerospace-Vehicle Walls.

This section contains the characteristics of materials used in the design of skins for both hypersonic aircraft and space vehicles. Some sources also include information on overheating and the structure of heat-protective systems.

In answer to a question as to what had to be done to launch a manned vehicle into space, Professor V. Dobronravov states: "Much had to be done. First of all, high-strength materials capable of withstanding the extreme temperatures encountered during reentry through the dense layers of the atmosphere [had to be developed]. This was accomplished through metallurgy." [73] On this same subject, B. Danilin states: "Heat-resistant materials must be developed for the shell of the space vehicle. Apparently, ceramics, metal oxides, and new plastics will play a role in this problem." [74]

In a discussion of heat conductivity and materials, A. N. Ponomarev states: "Low heat conductivity is the main disadvantage of the new materials discussed below. This leads to overheating of individual sections of the structure and to a decrease in their strength, and in addition causes high thermal stresses. For instance, at a speed of Mach 3, thermal stresses in the wing can reach a magnitude of 50--70 kg/mm<sup>2</sup>."

"Titanium alloys can withstand a temperature of 450°C; this limit can be increased to 650°C. Stainless steel withstands a temperature of 550°C, and work is now [1959] being conducted to increase this temperature to 650--750°C. Molybdenum alloys are the most heat resistant. Existing molybdenum alloys can withstand temperatures up to 860°C. At present, a titanium-molybdenum alloy, which oxidizes much less than other alloys, is the best. The temperature limit when molybdenum alloys are used can be increased to 1500°C. A low expansion coefficient, which provides for minimum thermal stresses in parts, is the main advantage in molybdenum. At present, molybdenum is widely used in rocket power plants. Ceramic materials, which include pure ceramic materials and cermets, have a very high melting point but are very brittle.

"A vehicle of special design made from heat-resistant materials can withstand the overheating due to high temperatures caused by air drag. For instance, a honeycombed material made from stainless steel, titanium, and other metals can be used for the design of this vehicle." [15]

R. G. Perel'man, discussing skin temperatures, states: "Deflect the heat from the skin or leave the skin as it is and isolate it from the 'insides' of the aircraft? Designers and engineers are working on both problems....The concept of a 'sweating skin,' which could be made from porous stainless steel, has been proposed.... Other methods which protect the skin itself from high temperatures are also known. The skin is sheathed with a material which has low heat conductivity and high heat resistance -- for example, glass wool, asbestos, fiber glass, etc. At an altitude of 6 km and a speed of Mach 4, the skin can heat to almost 700° in one minute. A 5-mm insulating layer of magnesium oxide increases the time to 10 minutes, while with a 25-mm layer of glass wool the temperature of the skin attains 220°, and then only after a half hour.

"At altitudes of 100 to 150 km, an aircraft can fly with a speed of about 10,000 km/hr without overheating for at least several hours. Terrestrial aviation is limited to speeds of about Mach 10 to 20 and altitudes of 100 to 200 km. This range of speed and altitude is the area of future aircraft development.

"It has become necessary to reject duralumin, the principal aviation material. At Mach 2.8 (corresponding temperature, about 250°) the strength of duralumin decreases twofold.... An increase of 1 kg in the structural weight of a fast single-seat aircraft results in an increase of 10 to 15 kg in the airborne weight. Therefore, duralumin is being replaced by titanium and its alloys. A noticeable drop in the strength of titanium starts at temperatures above 300° (approximately Mach 3), and of its alloys, at 400° (Mach 3.5)." [63]

Discussing the use of fiber glass in aircraft, A. Shternfel'd states: "On Tu-104 aircraft there are about 120,000 different parts made of plastic, rubber, and plexiglass. Of particularly great value is fiber glass, which

consists of glass fibers permeated with a synthetic resin which transforms [the whole] into a solid mass. In strength, glass plastic is comparable to steel and is about three times lighter. It is not subject to rust and does not require painting." [21]

In describing materials for aircraft bodies (aluminum, titanium alloys, and stainless alloys), reference 61 mentions: "Stainless steel, to a certain degree, can provide strength in the flight of an aircraft at ground level at a speed of about Mach 4. Higher speeds by special rockets require the use of new materials.... There are some materials obtained by the sintering of carbides or oxides combined with metals which are capable of working at temperatures of about 1000°C." [61]

In a discussion of the launchings of the first, second, and third Soviet artificial satellites, reference 61 states: "Calculations show that in the entry of an artificial earth satellite into the atmosphere at a speed of 6.4 km/sec, the heat flow across the frontal surface of the satellite is 33.5 kcal/cm<sup>2</sup> sec, which is 10 times greater than the heat flow across the narrowest section of a rocket engine. For comparison, we present the following data: after prolonged exposure to radiation of 0.7 cal/cm<sup>2</sup>, wood ignites spontaneously; when heat flow intensity is 1.35 cal/cm<sup>2</sup> for 8 seconds, thick oak boards ignite spontaneously. Heat flow across the frontal surface of a satellite exceeds the above values by 25,000 to 30,000 times. To cool a satellite having such a flow is impossible. Protection of a satellite from burning up is possible, if by reason of sublimation, a portion of the body constructed of a special ceramic, such as beryllium oxide, is transformed into the gaseous state. Beryllium oxide becomes gaseous at a temperature of about 2500°C. At 2500°C, 1 kg of beryllium oxide absorbs 5870 kcal of heat. Structural integrity can be maintained if about half of the satellite's weight, representing the outer shell of the satellite, is transformed into the gaseous state.... Besides beryllium oxide, other materials with melting points sufficiently high can be used for the outer body of a satellite or the warhead of [an intercontinental ballistic] missile. These materials include, for instance, carbides (compounds with carbon) of hafnium and tantalum (mp, 3900°C), titanium carbide (3150°C), and magnesium oxide (2800°C). Besides

the above-mentioned materials, the body of a recoverable satellite can be made from various plastics which, when heated to a temperature higher than their melting point, form a liquid or liquid-gas film which sharply decreases the heat transfer to the body of the satellite." [61]

In a report on the Eighth Mendeleev Congress in Moscow, V. A. Kopeykin states: "In April 1959, the Eighth Mendeleev Congress on General and Applied Chemistry convened in Moscow. A report by P. S. Mamykin and N. V. Zinov'yev gives the results of research on the ceramic and refractory properties of the chromite-alumina system.... The end products of a given powder which has been sintered at 1450° have the following properties at 1650°: apparent strength, 15.4%; strength in compression, 7.5 kg/cm<sup>2</sup>; and deformation, at 1520° under a 2 kg/cm<sup>2</sup> load.

"Ye. Ya. Antonova and A. A. Appen reported on a new type of refractory glass-metal coating for steel which protects against the oxidizing effect of air at high temperatures. As metal components the authors used powdered chrome and nickel, and as a binder, specially developed nonalkaline glass. A coating approximately 0.1 mm thick composed of glass and chrome in a ratio of 1:4 protected the steel against oxidation at 850 to 900° for more than 300 hours." [75]

In discussing vehicle configuration, B. Danilin states: "A blunt-nosed vehicle will be heated to a lesser degree than a pointed one. The shock wave, in effect, breaks away from the vehicle, taking a part of the heat with it." [74] V. Votyakov and B. Shumyatskiy expand on this idea by stating: "A pointed forebody reflects only 50% of the heat energy. If the forebody is made to have a blunted shape, then the powerful shock wave occurring in flight will act as a brake and will permit the rocket to deflect into the atmosphere more than 99% of the heat energy arising in the shock wave... Rough surfaces have more radiative ability than polished surfaces. For example, rusted steel radiates one and one half times more heat than polished steel." [64]

Engineer K. Malyutin in describing cooling systems states: "A system of cooling by means of sweating is based on the physical law of the latent heat of vaporization. The shell of the forebody of a ship is made with a double wall,

like the jacket of an internal combustion engine. Coolant is pumped into the jacket space. The surface of the rocket's cone is porous.

"The coverings of spaceships consist of laminated materials. For the basic layer, an alloy is used which provides the required structural strength. The succeeding layers must withstand very high temperatures and must be sufficiently strong so that the air does not 'wash away' or destroy the covering. Alloys and materials used for this purpose have the lowest possible heat emission coefficients. Together with the basic layer, fiber glass, high-temperature phenol resins, ceramic coatings, etc. are used as coverings for spaceships.

"In another system, cooling occurs as a result of burnoff or melting of the surface layer. In this method, the surface of the spaceship's forebody is covered with material of high heat-absorbing capabilities, for example, beryllium. Such coverings or coatings are capable of preventing heat penetration to the cosmonaut's cabin. In this instance, the walls of the spaceship may be made double [double skin effect] and of some heat-resistant material." [3]

Relative to heat-protective shell coverings, Yu. Sushkov states: "The shell of a recoverable satellite can be coated with high-melting materials with low heat conductivity. In this case, the heat should be eliminated from the satellite by some means. Plastics can be used for protecting the satellite against heat; the surface of a satellite covered with a 6-mm layer of beryllium oxide is heated to a temperature of 500--500°C after one minute in its fall through the air. If the surface is covered with an additional 2.5-mm outside layer of plastic, this temperature will be decreased by about 100°C." [59]

Following a statement that about 13 minutes are required for reduction in speed from orbital velocity to zero, G. I. Pokrovskiy continues, "During this time, bodies entering the atmosphere, for example, meteorites or spaceships returning to earth, heat up to a comparatively small depth. In a moving body heated by air,

the heat is transferred from the surface to the interior of the body. Also, a significant amount of energy is radiated outwards. Besides this, at high temperatures the surface layer of a heated body melts and partially vaporizes. Drops of melted material and vapor, containing a great amount of thermal energy, are drawn off by the force of the air flow, carrying this energy with it without giving it a chance to penetrate the medium." [57]

Reference 6 contains a graph showing the change in aircraft skin temperature for flights at 6 and 36 km at a speed corresponding to Mach 4, without cooling, and states: "If the stagnation temperature of the boundary layer is  $750^{\circ}\text{C}$  at an altitude of 6 km, the surface temperature reaches  $670^{\circ}\text{C}$ . At an altitude of 36 km, the surface temperature is considerably lower -- approximately  $300^{\circ}\text{C}$ .... From the graph, it can also be seen that an uninsulated surface in flight at a 6-km level heats up to a temperature of  $670^{\circ}\text{C}$  very rapidly (in about 1 min). If a 6.4-mm covering of magnesium oxide is used as heat insulation, the temperature reaches  $670^{\circ}\text{C}$  after 10 minutes of flight. If glass-base textolite 25.4 mm thick is used for insulation, heating of the surface to a temperature of  $300^{\circ}\text{C}$  takes 30 minutes.... For flight at an altitude of 36 km, an uninsulated surface heats to  $300^{\circ}\text{C}$  in about 20 minutes." [61]

Discussing the flight of the fifth ship-satellite, Yu. Sushkov states that in the question of combatting the overheating of the reentry vehicle two main problems are of note. The first is to provide strength to the ship's body to protect it from melting and the second, to decrease the amount of heat penetrating into the cabin, thus preventing high temperature increases in the cabin. The means of solving these tasks are closely related. For instance, overheating of the ship's surface can be prevented if it is covered with a layer of high-melting low-conductive material. But since the heat should be absorbed, a thick front wall made of metal with a high heat capacity can be used on the ship as an absorber of heat flowing from the air cushion to the cabin.

From reference 58 it is apparent that the aluminum nose cone of a rocket starts to melt at a velocity of Mach 5. At Mach 6, particles of molten metal break away from even a steel nose cone.

Discussing alloys used on hypersonic aircraft, V. Votyakov and B. Shumyatskiy state: "Aircraft fairings made of aluminum-based alloys lose a significant portion of their strength at 200°C. Titanium-based alloys keep their strength up to temperatures of 400°C. The fairings of hypersonic aircraft must be made of heat-resistant steels and nickel-based alloys. These materials resist overheating up to temperatures ranging from 800 to 1100°C.

"Heat insulating coverings or coatings must possess high heat capacity, i.e., the ability to absorb heat, and at the same time have low heat conductivity. It is important that they be light, plastic, that they hold firmly to the skin [of the vehicle], that they not break up under aerodynamic forces, and that they not burn up.... A gradually melting or vaporizing covering will absorb a large amount of heat, thereby preventing the aircraft from burning up." [64]

Zhovinsky, in describing the cooling of aircraft, mentions a graph which according to him "shows the change in inward heat flow for an aircraft whose wall temperature is maintained at 37°C through cooling. Flight speed corresponds to Mach 4 at various altitudes. Insulation has very little effect at high altitudes. For flight at low altitudes, an insulation layer on the surface greatly helps to reduce heat flow. At an altitude of 20 km, magnesium oxide insulation about 6.5 mm thick reduces the inward flow of heat in an airplane by two times. Glass-base textolite insulation 25 mm thick reduces the amount of heat transferred from the boundary layer inwards to the aircraft by 20 times. At lower altitudes, the difference obtained is even more significant. At altitudes of 50 to 60 km, the difference in heat flow with or without insulation is very small." [61]

The following statement appears in a description of the Space Pavilion at the Exhibit of the Achievements of the National Economy of the USSR: "Streamlined rockets in glistening whiteness stand rigidly at the entrance like sentries. In the [exhibit] hall lies their sister..with blackened, scorched metal protective shielding torn to shreds, and a thick fringe of parachute fabric." [76]

Describing the testing of a small rocket, reference 61 states: "The rocket was covered with glass fiber, which serves as a good heat-insulating material." [61]

In a description of cosmonaut training, Ye. Petrov mentions that the Vostok spaceship is constructed of metal and that during flight its skin temperature reaches 1000°C: "The spaceship was in a raised position, slightly above the floor, and its new metal glistened. Each involuntarily wondered: 'Will this alloy hold up when it is subjected to a thousand-degree temperature at the moment of reentry into the atmosphere?'" [77]

Describing the Gagarin flight, references 53, 2, and 22 give the following data relative to the reentry of Vostok-1: "The cabin has a special, external, heat-resistant insulation.... The portholes are equipped with heat-resistant glass and are protected by shutters which can be opened and closed electrically or manually." [53] "The material used for the portholes was probably rock-crystal, with a melting point amounting to about 1500°C. Thus, it is among the most heat resistant of all materials." [2] "The ship is girded at the joint between the cabin and the instrument section by a green belt, a coating with given optical properties which helps maintain the necessary temperature aboard the ship during its flight in space." [22]

In a discussion of the Vostok-1 flight, A. Il'yushin states: "Hypersonic gas flows act on a spaceship as it enters the atmosphere. High heating, overloading, and vibration of the rocket's skin can lead to its destruction.... During the rapid flight of a spaceship, strong shock waves occur. As a result, a dangerous high-temperature boundary layer is formed near the skin of the rocket. The development of special heat-resistant facing and an external shape for the spaceship which would provide the least drag in a medium and decrease the temperature of the boundary layer is one of the principal problems facing scientists and designers. Also, it will be their job to work out many other problems related to the gasdynamics of supersonic velocities." [50]

V. Borisov, describing the Vostok-2's heat shielding, mentions: "The surface of the Vostok-2 was covered with a special layer of heat shielding, which prevented the cosmonaut's cabin from burning during the high heating experienced during reentry into the dense layers of the atmosphere." [66]

P. Vasil'yev, in his description of the Vostok-3 and Vostok-4 flights, speaks of reentry as being the most difficult stage of the flight. Discussing the overloads experienced during reentry, he states: "Proper selection of the shape of the forebody of the ship-satellite is of great importance. "Coatings of refractory metals are used to

prevent burning up of the ship-satellite's body." [48]

## 2. Protection of Space Vehicles by Ablation and Sublimation

Ablation and sublimation are considered by Soviet specialists as the principal means of protecting aerospace vehicles from overheating. This section contains the principles and a general description of the ablation process. Some of the material has been taken from sources whose subject matter relates directly to the Vostok-3 and Vostok-4 flights.

From an article by I. A. Merkulov on the Vostok-3 and Vostok-4 flights, it follows that if a ship enters the dense layers of the atmosphere at a speed approaching orbital velocity, it is subjected to great heating and has to be equipped with reliable shielding so as not to burn up in the same manner as a meteorite. [14]

In an article written in connection with the Vostok-3 and Vostok-4 flights, N. Ushakov states: "A shock wave forms in front of a flying body.... A 'cushion' of compressed air, whose temperature attains several thousand degrees, originates between the shock wave and the forebody of the descending ship. Heat from this superheated air partially dissipates in the surrounding space and partially transfers to the spaceship, thus heating it....

"Smooth deceleration of a descending spaceship is one aspect of the reentry problem from space to earth. Another aspect, and probably the more complex, is the task of cooling the spaceship....

"Two problems must be solved to prevent the overheating of a descending ship-satellite. The first is to assure the durability of the ship's hull, not to let it melt. The second is to lower to acceptable limits the amount of heat penetrating to the interior of the ship. The means of solving these problems overlap. For instance, overheating of the ship's hull can be prevented by covering it with a layer of refractory material or material with low heat conductivity. With this, the transfer of heat to the cabin will be decreased.... A cabin with a thick front wall made of a material with a high capacity could serve as a heat absorber between the superheated 'air cushion' and the cabin. However, because of the weight factor, this is not the best method.... Substances exist which under heat are transformed directly from the solid state into the gaseous state. A thick layer of such a substance on the frontal surface of a

spaceship can provide a sufficiently thick gaseous layer and effectively protect the ship from overheating." [49]

The following material was taken from a book by Professor G. I. Pokrovskiy published in 1962; it contains some data on ablation and the indication that it is possible to reproduce the effect of media on a body moving at a velocity approaching 10 km/sec. Pokrovskiy states: "Electrons, the basic transmitters of energy in hypersonic motion, are known to be negatively charged. In transmitting energy, electrons also transmit electrical charges. As a result of movement at a high velocity, a body is charged to a high potential by negative electrical charges. However, another process counteracts this process -- electron emission by a highly heated body, i.e., the discharge of electrons from a body having a high temperature...."

"Ablation is more intensive when the material of the body in the plasma flow is low melting and heat conductive. However, in a number of cases there are sharp, and at first unaccountable, deviations from this rule. For instance, if two completely similar spheres are placed in a plasma, one copper and the other paraffin, then it would be expected that the paraffin sphere would experience much more significant ablation than the copper. However, experience has yielded just the opposite result. It has been shown that it is possible to select a distance away from an electric explosion at which the copper body is subjected to intensive ablation, while at the same time, the paraffin experiences no noticeable changes in its surface.

"This phenomenon can only be explained by the fact that the plasma transfers its destructive energy through electron flow to the body around which it flows. If these electrons strike a body which is an electrical insulator, they charge the surface with negative electricity, which has no place to go. This immediately weakens the influence of the plasma on the body.... The electrons experience such repittance that they decelerate and strike the surface of the body very weakly or not at all...."

"Besides, not only an electrical charge can serve as shielding against plasma, but also a sufficiently strong magnetic field can be used.

"Ablation intensity is evaluated in various ways. The simplest and most descriptive is the determination of the mass

removed in a unit of time from the nose section of a body moving at hypersonic velocity. It can be considered that the energy carried by an oncoming air flow for a unit of time (the power of an oncoming flow) is proportional to the density of the air, the section of the moving body, and the cube of the velocity of the movement.

"The power of an oncoming flow can be conveniently seen in the simplest of examples, when the cross section of a moving body is equal to a unit -- for instance, one square millimeter. In this case, the power obtained can be called the density of the power of the oncoming flow. The density of the power of the oncoming flow for normal air density is equal to 1 kw/m and is obtained at a velocity of approximately 11.7 m/sec. Therefore, the density of the power (W) at any other velocity is

$$W = \left(\frac{V}{11.7}\right)^3 \text{ kw/m}^2,$$

where V is the velocity of the body (the oncoming flow), expressed in m/sec.

"The above formula is suitable for a case of movement in air having normal density, i.e., near sea level. In the first approximation, it can be considered that the value W will decrease by two times for every 5-k increase in altitude.

"It has already been shown that the interaction of a moving body with the surrounding medium can be of two types. First, there is interaction with the individual molecules, and second, interaction with a continuous medium.... The boundary between both types of interaction of a moving body with a medium is at an altitude of 83 k if the diameter of the body is equal to approximately 1 cm....

"The mass of the ablation products moves within the limits of a cone which is more or less symmetrical relative to the axis of the resulting crater. The direction of discharge of ablation products depends little on the direction of molecule impingement.

"For the above type of ablation-product discharge, the cone which is formed becomes somewhat like the exhaust nozzle of a jet engine discharging a stream of gas. This means that in the ablation of the forebody of a moving object, an additional force is created which opposes the movement and produces an additional decelerating effect on the moving object besides that of ordinary aerodynamic forces....

"The reactive effect of the ablation products will greatly exceed the decelerating effect of the air molecules. Therefore, the increase in the mechanical effect of the oncoming flow of air must be very significant in ablation. Computations indicate that in this case resistance to movement will be determined not only by ordinary aerodynamic forces, but also by the reactive effect produced by the ablation of the moving body....

"The sound barrier, whose study has played a major role in the development of aviation, cannot be considered as an essential when compared with the reactive effect occurring at hypersonic velocities during ablation of a moving body.

"In the case of ablation, additional resistance arises which is also proportional to air density and velocity and the cross section of the moving body. However, this resistance is proportional not to the square but to the cube of the velocity of the movement. Additional resistance begins at speeds of 1 to 3 km/sec, depending on the heat resistance of the moving body. At a speed of about 8 km/sec (escape velocity), additional resistance may exceed aerodynamic resistance by two to four times.

"Therefore, for space velocities in a sufficiently rarefied gas, the theory of the reactive effect of ablation should be used as the basis of resistance calculation, as opposed to the use of classic aerodynamics....

"The discharge of a capacitor through a thin wire produces a powerful electric explosion. The vaporized wire forms a small plasma cloud which expands in all directions at a speed of several kilometers per second. If a body is placed in the path of the expanding plasma, the plasma will flow around the body.... It is possible to reproduce the effect of media on a body moving at a velocity approaching 10 km/sec." [57]

### 3. Cooling Systems.

This section contains material on the cooling of space vehicles by sublimation, ablation, porous cooling, and cooling with a magnetic field.

In his article, "The Heat Barrier", Engineer V. L'vov writes: "The simplest method is to construct the vehicle of material that can withstand high temperatures and to shield the vital instrument compartments with heat-resistant plating. Another method is to design a special cooling system using liquid fuel or water as the coolant. A new so-called porous cooling method is of interest. In this method, liquid is introduced to the heated surface of the vehicle through small pores, or openings, in the skin; as the liquid evaporates, it covers the surface with a thin film of steam which safeguards the metal from melting. An unusual method of shielding the vehicle is one which permits melting. In this case, although the metal melts, it melts according to the 'plan' of the designer." [58]

A porous cooling system can be used in a recoverable satellite; one liter of water will prevent 9 kg of steel shell from melting. [59] Hydrogen, helium, or water can be fed through the pores. [74] Ponomarev states that liquid cooling through the pores of the shell is possible, although there is a danger of the pores becoming clogged. [15] The front part of the satellite can be covered with beryllium oxide. The heat of evaporation of 1 kg of beryllium oxide is equal to that of 90 kg of the satellite shell. [59] G. A. Tirskiy has discussed a mathematical solution of the heat flow around the heat-conducting shell located behind the moving shock wave. [3] According to Ponomarev, sublimation is a very promising cooling method. Molybdenum, tungsten, platinum, and gold undergo sublimation under conditions of high temperature and pressure. The latent heat of sublimation can be used for vehicles which fly at very high speeds. Therefore, it is possible that the materials mentioned will be used for the nose and for the leading edges of the wings and tail surfaces. Ponomarev also states that; in the opinion of several specialists, the use of gold for cooling of electronic devices can be cheaper than other cooling methods. [15]

According to Votyakov and Shumatskiy, "... cooling of the skin by means of the evaporation of water is highly promising. Water is released to the surface through pores, or special holes, in the skin; there it evaporates. Six to seven times more heat is absorbed with water evaporation than in ordinary cooling without evaporation." [64] In a further discussion of the porous cooling system, Malyutin states: "Because of the excess pressure being created, the coolant is forced outwards. Passing through the pores in the heated shell, the liquid is transformed into the gaseous state with an enormous amount of heat being expended on vaporization." [3]

Several sources mention internal cooling systems for aerospace vehicles and give the following indications in this field. The heating of a rocket or satellite can be decreased by a special cooling system using fuel or water as the cooling agent. [59] Internal cooling of a space vehicle's shell is possible by the use of lithium or sodium. [74] According to Ponomarev, fuel can be used as the cooling agent in the internal system. The effect of this system, however, is decreased at high speeds during long-range flights because of the high consumption and heating of the fuel. [15] Reference 64 states that besides protective coatings to cool the surface of an aircraft it is also possible to use liquid cooling. For this, the use of liquid fuel is proposed. [64]

Information on cooling by means of a magnetic field is given by several Soviet authors. Reference 64 states: "In trying to prevent aerodynamic heating of aircraft, highly promising are the achievements of a new science -- magnetoaerodynamics. Powerful magnetic fields can act upon shock waves in order to force the heated layer of air away from the leading edges of the aircraft." [64] In 1958-1959 sources, Soviet authors mention that the electrical conductivity of the ionized air in front of a flying body is increased if ionized materials, e.g., sodium or potassium, are sprayed into the ionized air. It is calculated that at speeds of Mach 10--12, the conductivity of the air is several times higher than that of sea water. [56] According to Sushkov, the decelerating effect of the magnetic field will be increased if the nose of the satellite

is covered with highly ionized materials. [59] The shock wave in front of the body, in which the main volume of heat is concentrated, can be separated from the body by the magnetic field. [74] In subsequent literature (1961-1963), the interest of Soviet specialists in the utilization of magnetic fields in braking and cooling systems is also mentioned. In discussing reentry methods, I. Yavorskaya writes: "One other interesting and more advanced system of braking has been developed in recent years -- the setting up of an intense magnetic field around the spaceship to deflect the ionized air stream flowing around the ship. This produces much resistance and at the same time reduces heat transfer to the ship's skin... Reentry methods were systematically studied and tested by Soviet scientists in a long series of satellite and high-altitude rocket shots." [78]

In a discussion of the development of new hypersonic aircraft, Chief Aircraft Designer A. I. Mikoyan states: "It is evident that when flight at hypersonic speeds is attained, besides the difficulties connected with overcoming the 'heat barrier,' it will be necessary to solve many new problems such as the advantageous use of the phenomena of dissociation and ionization of air. The latter has much promise for dealing with electromagnetic flow about the surface of an aircraft." [62]

## SECTION F. LANDING SYSTEMS

### 1. Two Landing Methods for the Cosmonauts.

According to a TASS report on the Gagarin flight, the cosmonaut in the Vostok can land by one of two methods: in the cabin or by ejection from the cabin in the pilot's seat. The method calling for landing in the cabin was tested on the fourth and fifth ship-satellites. In the second method, the pilot's seat is ejected from the cabin at an altitude of about 7 km and lands by parachute. [11] Describing the Gagarin flight, L. Mar'yanin states: "The landing...can be accomplished both in the ship and separately by using the ejection seat or the parachute, since, in the latter case, the ship can land safely by itself. The landing of the ship was tested repeatedly with ship-satellites. During these flights, the test dogs Chernushka and Zvezdochka were landed safely in the ship." [23]

From an article by Gagarin, it follows that the landing of the cosmonaut in the ship's cabin is the principal design variation in the landingsystem. Describing his flight, Gagarin quotes the Chief Designer: "'The cosmonaut lands in the ship's cabin,' the Chief Designer told us, 'but, at the same time, we have provided an alternative, whereby he can leave the ship if necessary.'" [79]

Gagarin landed in the ship's cabin; this was mentioned by several authors, including Gagarin, who, in answer to questions at a press conference, mentioned that during the landing "the pilot was in the cabin." [80]

From recent sources, it is apparent that landing the cosmonaut by ejecting the pilot's seat from the cabin is considered by Soviet specialists as having more advantages than landing in the cabin. In describing the design of the Vostok-3 and Vostok-4, a TASS report states: "During descent from orbit, the cosmonaut has the option of landing in the cabin or ejecting with the seat from the cabin at a low altitude and landing by parachute, independently of the ship. Parachute landings by cosmonauts independently of the ship have a number of advantages for landings made on solid ground, where the landing conditions can be complicated by terrain features, wind, etc. Therefore, for the group flight, as for the Vostok-2 flight and according to the wishes of the cosmonauts themselves, the flight program included the opportunity for the cosmonauts to land independently of the ship. It should be mentioned, however, that for all flights (including the group flight), the spaceship-landing system functioned normally, and the ships landed in perfect condition." [53]

## 2. Landing Method for Vostok-Type Spaceships.

From several sources, it follows that all Vostok-type spaceships landed by parachute. Discussing his flight, Gagarin states: "When the parachute\* opened above me and I felt the strong shroud lines, I began to sing." [80] Additional evidence in support of this follows from a description of the Vostok-1 landing by an eyewitness, who observed the ship in the sky for some time. Having heard and seen the Vostok-1 in the sky, "Officer Cassiyev quickly ordered a car and, taking several people with him, sped along the road.... They drove and watched the ship until it went down beyond the woods." [81]

The Vostok-2 probably also landed by parachute; this is evident from an eyewitness report which states: "In the sky a huge descending object appeared: Isn't it the Vostok?." [82]

In describing the Vostok-3 and Vostok-4 flights, Design Engineer I. A. Merkulov states: "When the speed of the spaceship is greatly reduced by the retro-power system and air resistance, it is possible to deploy a parachute and lower the ship smoothly to earth." [14]

Other data related to the landing method are given in references 81, 82, 68, and 83. In particular, the translations and abstracts below contain statements showing that the Vostok-2, Vostok-3, and Vostok-4 spaceships landed not far from the landing points of their respective cosmonauts and that the landing speed of the Vostok-1 and Vostok-2 was only 5 m/sec. Reference 53 gives data that makes it possible to calculate the distances between the landing points of the Vostok-3 and Vostok-4.

Private Goncharov, an eyewitness to the Vostok-1 landing, said: "It was a clear spring morning. Trees and shrubs were being planted in the camp area. Suddenly an explosion was heard, like that of an aircraft breaking the sonic barrier. Immediately, a flying vehicle was noticed." [81] An eyewitness to the Vostok-2 landing said: "In the morning we heard a noise, like that of thunder, and then in the clear sky we saw the spaceship coming in for a landing." [82]

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\*) The parachute mentioned in Gagarin's statement probably refers to the spaceship landing system and not to the pilot seat, because it is known that Gagarin landed in the ship's cabin.

After mentioning that Titov left his ship by seat ejection, reference 68 continues by stating: "Meanwhile, the Vostok-2 sped to its landing. After a while, it was lost from Titov's sight.... Passing through the clouds, the cosmonaut searched futilely for the familiar shape of his craft; no sooner had the white clouds dispersed than the harvested fields shone yellow below. He quickly saw the ship glistening in the sun.... At that moment Titov's parachute swung around.... To one side of a railway bed the spaceship had come to rest.: [68] A. Romanov, in his description of the Titov and Vostok-2 landings, states: "Before taking his seat in the Pobeda, Titov asked permission to return 'home' to get his documents. 'Home' was the cabin of the spaceship." [82]

From an article by Titov it follows that after the landing he got into the car which was to deliver him to the district committee, but he asked that he be taken first to the ship. The ship was located on the other side of a railway embankment. They sped through a crossing and Titov saw the Vostok-2 standing in a field. The people from the landing support group were already standing around the ship. Entering the ship, Titov took the ship's log and had a drink of water from the supply in the cabin; he then left for the district committee in the same car. [28]

G. Ostroumov visited the pilots who found Nikolayev and Popovich; he states: "'I suddenly saw something shining against the gray-green background of the earth', said the one who found Nikolayev. 'I descended. I saw the spaceship and a man walking near it. He waved his hand. I flew even lower and saw that it was Nikolayev.' The other's story was almost exactly the same." [83]

From an East German source it follows that the Vostok-1 and Vostok-2 landed at a speed of 5 m/sec, a value not found in other sources. The author of this book states: "The Vostoks I and II, which reached a velocity of 8 km/sec, were able to orbit around the earth for a relatively long time. After orbiting, it was necessary to steer them into a reentry path in order to bring them back to earth. Also, the 8000-m/sec velocity had to be reduced to a normal parachute-landing velocity of 5 m/sec." [2] The author compares the speeds above with those of the U. S. Mercury flights by Alan Shepard and Virgil Grissom and states: "After orbiting, the 8000-m/sec orbital velocity of the Vostoks had to be reduced to the normal parachute landing velocity of 5 m/sec; the velocity of the U. S. Mercury capsule was reduced from only 2.0 km/sec to 10 m/sec." [2]

Discussing the reentry and recovery of the Vostok-3 and Vostok-4 on 15 August 1962, source 53 states: "According to the program, the ships were to land in Kazakhstan at lat 48°N. The retroengine system of the Vostok-3 was switched on at 0924 hours Moscow time, and six minutes later the retroengine system on the Vostok-4 was switched on. According to corrected data, Nikolayev landed at 0952 hours, and Popovich landed at 0959 hours. Both cosmonauts landed close to their ships." Their precise landing points are given as follows: Nikolayev, 48°02'N, 75°45'E; Popovich, 48°10'N, 71°51'E. [53]

### 3. Landing Methods for Cosmonauts.

As is known from Section F, paragraph 1, two methods are employed for landing Soviet cosmonauts: in the spaceship cabin or by ejection of the pilot's seat from the cabin. This section of this report deals primarily with the ejection method.

Describing aircraft ejection systems, K. K. Platonov gives some general information on ejection. According to him, "experience has shown that at speeds exceeding 500 km/hr, a pilot does not have sufficient strength to overcome the slipstream and leave the cockpit of an aircraft.... In this case, the necessity arises to automatically eject (catapult) the pilot with his seat from the aircraft's cockpit....

"Parachutists in a delayed-opening jump also must contend with an onrushing flow of air. The parachutist's rate of fall increases initially, but after 10 to 20 seconds (depending upon the altitude), it becomes constant, the so-called terminal velocity being attained. In a delayed-opening jump from an altitude of 2000 to 4000 m, terminal velocity is attained after 11 or 12 seconds and is equal to 50 m/sec, whereas in a jump from 12,000 m, it is attained after 18 or 20 seconds and is equal to approximately 90 m/sec." [84]

Figure 138 in reference 84 shows the ejection sequence from an aircraft with the following procedural notes:

1. Place feet on footrest of seat.
2. Pull on shoulder straps and jettison canopy.
3. Straighten back and brace against back of seat.
4. Hold breath, clench teeth, close eyes, and eject.
5. Push away from seat with feet.
6. Prepare for touch-down. [84]

The forces acting during ejection from an aircraft are given in Figure 139 of reference 84 as follows:

1. An initial acceleration force of 10 to 26 g's will be received from head-to-pelvis for 0.1 to 0.2 second.
2. A pressure exceeding 2000 kg/m<sup>2</sup> will be exerted from chest-to-back for 0.07 to 0.14 second.
3. An acceleration force of 10 to 26 g's will be received from back-to-chest for 2 to 3 seconds.
4. An acceleration force of 3 to 7 g's will be received from pelvis-to-head for 0.3 to 0.5 second. [84]

In his article entitled "If a Cosmonaut is in Danger," Yu. Marinin describes methods of rescuing a cosmonaut during all stages of the flight. For emergency situations arising during launching, the author describes the system used in American Mercury vehicles; he continues by saying, "another possible method of rescuing cosmonauts envisages the use of ejection seats, a principle long known in aviation." [29]

In discussing the Vostok-2 reentry, N. Mel'nikov and N. Kotysh state: "Titov, firmly pressed against the seat, fixed his eyes on the porthole. The hand of the clock approached the solemn mark, and Titov took advantage of the permission transmitted to him to use the catapult. A shot sounded. At that instant, the pilot experienced a lightning-like jolt. The catapult separated him from the ship. He was suspended under the cupola of the parachute." [68]

From an article by G. Anatol'yev, it is evident that Titov descended using an ordinary aviation parachute of the type presently in use in Soviet air units.

Some data on pilot ejection from spaceships are given in references 20 and 85. Reference 20, in a general description of the ejection of pilots from aircraft and spacecraft, states that the pilot's seat, and on spacecraft the entire cabin, is installed in the craft on guid rails. Three parachutes are attached directly to the seat or cabin: the first is the smallest, and the third, the largest. While ejection from an aircraft is an emergency measure, from a spaceship it can be one of the variants of normal landing. In an aircraft, the ejection mechanism is a small rocket located in a tube at the back of the pilot's seat; in a spaceship, the ejection mechanism can be somewhat different. The seat or cabin is ejected from the craft, and the first parachute,

whose only purpose is to prevent the pilot from somersaulting, opens immediately. The second or deceleration parachute is opened automatically by a barometric instrument at a given altitude. The third and main parachute is deployed only after the flyer has dropped below 3 km and can remove his oxygen mask or helmet. As it opens, the pilot is separated from his cabin or seat and completes his descent as would an ordinary parachutist. All the operations preparatory to ejection, the control of the ejection mechanism, and the opening of the parachutes are performed automatically. [20]

In a general description of a modern spacesuit, reference 85 considers it as a cabin within the cabin of a space vehicle, for it duplicates the latter's functions with respect to radiation shielding, microclimate, g-force protection, pressurization, and communication with the earth. This source also states: "In an emergency, the cosmonaut can return to earth with the entire cabin as a capsule or can be individually ejected; here, the spacesuit is irreplaceable." [85]

A TASS report on the Vostok-2 flight states exactly the landing method used by Titov, saying, "It is possible to use two methods in pilot landing: in the ship, and independently of the ship, i.e., by separation of the seat with the cosmonaut from the ship at a low altitude with subsequent descent of the cosmonaut by parachute. In his flight, Titov used the latter method." [71]

From reference 24 it follows that cosmonauts Nikolayev and Popovich used the same method as Titov. Popovich states: "I landed in the same manner as G. Titov and A. Nikolayev, i.e., near the ship.... I landed about 200 kilometers away from Nikolayev." [24] Bykovskiy landed in the cabin. [99]

For references 71 and 86, it follows that the Vostok-2 and cosmonaut Titov landed at the same time, and four minutes elapsed between the time the Vostok-2 appeared in the sky over the recovery area and its landing. According to reference 71, "the Vostok-2 and cosmonaut Titov landed in the designated area. This occurred at 10:18 Moscow time in the vicinity of a settlement called Krasnyy Kut in Saratovskaya Oblast." [71] Reference 86 mentions: "At 10:14, in the sky over the recovery area, the spaceship appeared; several minutes afterwards, G. Titov already stood firmly on mother earth." [86]

#### 4. Space-Flight Command and Communications Network (Recovery Phase).

This section contains material on the space-flight command and communications network, with particular emphasis on the recovery phase. On the basis of the information contained below, an organization chart has been compiled depicting the structure and chain of command of organizations directly connected with Soviet manned space flights. Primary attention has been given to those organizations participating in the recovery phase of manned space flight.

From a description by A. Trifonov of the Vostok-2 mission it is apparent that the Technical Director at the cosmodrome command point directs spaceship flights. The Technical Director and the State Commission are linked by telephone with the Coordination-Computer Center, which is probably located a relatively short distance from the Baykonur Cosmodrome. The Coordination-Computer Center receives information on the flight from points and telemetry stations located along the flight path. The center computes the necessary data and transmits it to the command point at the cosmodrome. The command point transmits the decision to bring the ship; however, the actual commands for the landing are transmitted to the ship by the points situated along the flight path. Describing the operation of the Coordination-Computer Center, A. Trifonov states: "The sixteenth orbit around the earth has been completed. The Technical Director asks whether or not the cosmonaut is ready to land.... In the Coordination-Computer Center, the final commands for the reentry of the ship have been calculated. The final data are reported to the Technical Director and the State Commission. Everything is ready and the decision to land the ship can be given.... The following first reports come in from the telemetry points: 'The commands for landing have been given.' Immediately after this, the steady voice of Titov comes over the loudspeaker: 'The commands for landing have been transmitted.' After a little while, the report comes: 'The retroengine unit has fired, has operated for exactly the required time, and has been switched off. Descent has begun.'" [87]

Military author Colonel F. Lushnikov discusses the function of the Coordination-Computer Center. From his article it is apparent that the staff of the computer center consists of military specialists. Describing the day of the Vostok-3 and Vostok-4 recoveries, Lushnikov states: "We are in the headquarters, which for three days has closely followed the course of events in the flight of the spaceships. Long before the

landing, intense work went on here: necessary corrections in the cosmonauts' landing areas were made. Somewhere on the concrete runways of distant airfields transports and helicopters stood at the ready, and a group of parachutists waited for the signal so that at the right moment they could go to the aid of the cosmonauts....

"On the huge globe with a model of the Vostok-3 moving about it, we can see that A. Nikolayev is now over East Africa and is beginning his 65th orbital pass around the earth. From the cosmodrome the announcement comes that the ship's retro-engines have been fired; the Vostok-3 is beginning its descent.... Continuous reports come in from the trackers following the spaceship flight; the data received are instantly corrected on the maps, and conventional symbols are put on the map. The tables are already crowded, and one of the maps has been spread out directly on the floor. The group of officers working here has quite a bit of experience. I had a chance to see these people at work when Cosmonaut-2 German Titov was making his landing. Everything is done quickly, but without commotion. The last names of the commanders of the crews assigned to locating the pilot-cosmonauts have been painted on plexiglass; the duty officer never takes the telephone away from his ear; he maintains communication with the cosmonauts. A minute passes..., another..., a third. According to calculations, Nikolayev should already be landing, but as yet no reports to that effect have come in. Finally, the telephone rings. Captain Moskalevic the commander of the crew which flew to rendezvous with Nikolayev, saw the ship from the air. 'The final signal from Popovich came in at 9:36.... A report comes in from one of the points: 'I hear Golden Eagle' is the message. A minute later, a bearing on the Vostok-4 is broadcast. As in the first case, calculations are made to determine Popovich's landing point; a new crew takes off to rendezvous with him.... The pilot, Captain Breus, dipped the wings of his airplane in greeting to the famous cosmonaut. Helicopters immediately flew to the Cosmonauts' landing points; these were piloted by Captains Bobrov and Zhilyayev.... The headquarters officers rolled up the maps.:

The Coordination-Computer Center is also mentioned in reference 88, in which it is called "the command point." From this source by A. Romanov it is evident that the Coordination-Computer Center functions under the leadership of the Deputy Chairman of the State Commission. Romanov states: "The correspondents arrived early at the command point, where the group for organizing the pickup of the cosmonauts after landing back on earth was situated."

"There is a large room, in the center of which stands a table with a large map on it. On the map, the flight trajectory of the spaceships has been drawn. The Deputy Chairman of the State Commission, scientists, and designers are bent over the table. At about 9:30, an announcement was made at the command point concerning the descent of the ships. After 15 to 20 minutes, there was a new report: Pilot-Cosmonaut-3 has been found. Soon a new announcement reaches the command point: Cosmonaut-4 P. Popovich has also been found.... The Deputy Chairman of the State Commission announces to the journalists the place where they can meet the cosmonauts.... G. Titov arrived at the command point.: [88]

Analysis of several sources describing the recovery of the Vostok-3 and Vostok-4 spaceships shows that the operations-group room mentioned by V. Gol'tsev and G. Ostoumov [89] is located in the Coordination-Computer Center and is referred to by other authors as the "big room" or "hall." The article by V. Gol'tsev and G. Ostoumov was written in the recovery area, relatively far from the Baykonur cosmodrome. Therefore, the phrase "one of the cosmodromes" mentioned in this article probably refers to the Baykonur cosmodrome complex. Gol'tsev and Ostoumov state: "Before one's eyes is the room of the operations group at one of the cosmodromes. Even several days ago when the celestial twins were only beginning their flight, we saw a map there. Red had been used to indicate the final orbits of the cosmonauts, the end of a space flight. Yellow paint lightly outlines the area where the group flight is to end. At that time, the map was hanging to one side.... What was in front of us was not exactly a map; rather, a featureless landscape of the very area which was outlined in yellow paint."

Further discussion by the authors of reference 89 indicates that they travelled from the headquarters of the command point to the headquarters of the recovery forces. Relative to this they state: "Last night, together with specialists and doctors, we travelled to the place where the landings were to take place. Again there was a map in front of us. It covered a large table in the headquarters of the recovery forces. We saw not only the final orbits of the spaceships, but also the calculated landing points indicated by two small symbols."

Describing the recovery forces, the authors state: "On the flight strips, powerful airplanes, ready to take off at the first signal from headquarters, are dying in anticipation."

Not far away detachments of helicopters are deployed.... A group of parachutists is in number one readiness [sic]. This group includes personnel in various specialties. At their disposal is everything necessary to ensure a safe rendezvous for the cosmonaut back on earth." [89] At the end of their article, the authors turn again to a description of the Coordination-Computer Center and state: "At the headquarters which was entrusted with the recovery of the spaceships, an almost 'space silence' [prevailed]. There are no irritating noises or lighting effects.... In the room of the Chief Navigator of the command point, there is a globe of such large dimensions that it almost fills the entire space between the floor and the ceiling." [89]

The headquarters mentioned above is called the "recovery command point" in reference 54. The authors of this source state: "We left for the recovery command point, which is situated in a white two-story building.... The Chief Navigator says, 'Everything is going according to the prescribed program.... In airplanes and helicopters experienced pilots are on duty around the clock, ready for the order from the command point to take off and go wherever required....' Operations workers follow the hands of the clock.... The first cosmonaut gave his call sign. The signal is received. Immediately, the order is given to the commander of one of the helicopters to fly to the place where Nikolayev landed. Popovich's signal was received here also." [54]

The headquarters of the recovery force mentioned by other authors is also mentioned by G. Ivanov as the "command point." In his description of the Vostok-3 and Vostok-4 recoveries, Ivanov states: "Next to the command point, in the shade of green acacia trees, there is a small one-story house. It is here that A. Nikolayev and P. Popovich will rest after their fantastic flight." [90] The headquarters of the recovery force and the small one-story house for Cosmonauts Nikolayev and Popovich mentioned above are located in the city of Karaganda. This conclusion is based on statements by A. Romanov and G. Ostroumov. A. Romanov states: "In order for them to get to their assigned quarters, the cosmonauts had to drive through a crowded, living corridor; thousands of greetings were heard." [88] G. Ostroumov states: "In their spacesuits, one after the other, Nikolayev and Popovich descend the access ladder of the airplane.... The heroes' plane is taken away to the farthest corner of the Karaganda airport." [83]

Reference 90 gives some information on the participation of local inhabitants in the recovery of Cosmonauts Nikolayev and Popovich. The First Secretary of the Karaganda Oblast Committee states: "When it became known that the recovery would take place south of Karaganda, we communicated this to all populated points.... There are no roads in this area and people hurried to the cosmonaut on foot, horseback, trucks, and several went by tractor. Naturally, the helicopter pilots left everyone behind." [91]

Some details on the meeting of Cosmonauts Nikolayev and Popovich with the recovery-force personnel are given in references 92, 83, and 93. According to Nikolayev, "The first to meet me was a doctor. He appeared several minutes after landing.: [92] G. Ostroumov supports this by stating: "Nikolayev was examined by a doctor within 25 minutes after landing.: [83] S. Borzenko and others state: "Almost the same things happened to A. Nikolayev that happened to P. Popovich. He was met first by a doctor and later, mounted Cossacks found him; collective farm workers rushed to him by tractor."

The participation of aircraft, helicopters, and automobiles in the search for the cosmonauts is mentioned in references 94 and 86. G. Ostroumov, describing Titov's landing, mentions "the activities of the official mechanism for bringing the cosmonaut from the recovery area to a populated point. The links in this mechanism are various -- aircraft, helicopters, radio.... The aircraft take to the air. They remain aloft so that when the first signal is given, they rush to the descending ship." [94] S. Beglov continues by stating: "At 9 o'clock in the morning on 7 August, the final orbit was completed. Everything was ready in the recovery area. Aircraft, helicopters, automobiles of all types and for all purposes [were ready]...." [86]

Some data on radio communication between the spaceship and the ground stations are mentioned by A. Trifonov in a discussion of the Vostok-2 flight. Trifonov states: "The Vostok-2 entered the dense layers of the atmosphere.... The onboard transmitter 'Signa;' ceased [operation] at 10:04.... Now, other transmitters must be switched on which operate at a low altitude and which are installed in the ship directly on the cosmonaut's seat; their signals, differing from the above-mentioned, signify: 'Everything is in order. The ship and cosmonaut are in descent.'" [87]

From references 83, 95, and 96, it follows that the cosmonauts report to the State Commission on their flight. The State Commission receives this report somewhere in a large city located along the Volga River, not far from the house in which the cosmonauts rested after their flight. In describing Nikolayev's and Popovich's rest in Karaganda, G. Ostroumov states: "On the morning of August 16th, the cosmonauts and their comrades went again to the airport. They left by plane to make their reports to the State Commission.: [83] S. Borzenko and N. Denisov continue by saying, "Today (16 August 1962) both cosmonauts, A. Nikolayev and P. Popovich, arrived in a large city on the banks of the Volga by special plane from the recovery area. The State Commission arrived by plane to hear the first reports on the scientific observations made in space and the details of the work performed during flight." [95] From reference 96, it is evident that after the Vostok-1, -2, -3, and -4 flights, the cosmonauts all rested at the same place. Discussing the Vostok-3 and Vostok-4 flights, the authors state: "At a scenic spot on the banks of the Volga, the cosmonauts settled down for a rest." [96]

## SECTION G. LUNAR FLIGHTS

This section contains material giving only general information on the launching, landing, and recovery of lunar space vehicles.

In an article entitled "The Roads of Lunar Seas," S. Nazarenko states that manned flight to the moon must be preceded by the launching of heavy space vehicles into outer space at escape velocity. Nazarenko makes this statement after a comparison of Soviet space-vehicle weights. According to him, "the previous Soviet ship-satellites, including the Vostok series, weighed approximately 4500 to 4750 kg. The heavy satellite launched on 4 February 1961 set a singular space record; it weighed 6483 kg. At the same time, the weights of the 'lunar' scientific and measuring apparatus with powersources and containers were 390.2 and 435 kg. The automatic interplanetary station launched towards Venus weighed 643.5 kg; the Mars probe weighed 983.5 kg; and 'Lunik' weighed 1422 kg. Outwardly, this is obvious progress; however, orbiting space-ships are still heavier than interplanetary vehicles by 5 to 7 times.... Practice has shown that [to provide] for man's normal vital activity, a spaceship should weigh about 4.5 to 5 tons. For a longer flight to the moon, the weight of the ship increases due to an increase in the amount of air, food, and water necessary. Therefore, manned flights to the moon must be preceded by the launching of heavy space vehicles into outer space at escape velocity." [97]

V. Demin, Candidate of Physical and Mathematical Sciences, discusses three methods of lunar landings. According to him, "three methods of lunar landing are being considered in cosmonautics."

"The first method is impact landing without slowing the ship down. In a flight to the moon, the ship's speed near the moon is between 2.5 and 3.3 km/sec.... The placing of the emblems of the Soviet Union on the moon is an example of a hard landing.

"Another method is a rough landing with a partial decrease in the rocket's speed. Using this method, when the rocket enters the moon's sphere of influence, automatic devices orient the axis of the rocket towards the center of a star and fire the rocket engines. At the moment of touch-down on the moon, the rocket should have a speed of [only] several hundred meters per second in order to withstand the impact with the surface.

Some details on lunar landings were found in reference 29 where the problem of cosmonaut reliability is discussed. Yu. Marinin states: "In a lunar landing, a spaceship will encounter various unpleasant surprises. The site selected for the landing may prove to be unsuitable, deceleration may not be sufficient, etc. Therefore, up to the very last moment, even as the ship touches the ground, it must have the capability of 'shooting upwards' and making the return trip to earth." [29]

In a description of lunar flight, Professor S. Nazarneko states: "There is a corridor above which the low density of the atmosphere does not provide effective deceleration, and below which increased density [carries] the threat of burn-up. At speeds approaching 11.2 km/sec, this corridor is very narrow and is measured in kilometers.... In principle, there is a possible variant for transforming a Lunik into a satellite prior to landing back on earth. In this case, the rocket must use its retroengines to reduce its speed from 11.2 km/sec to 8 km/sec; then, in the more widely tolerable corridor, the rocket decelerates, 'using' the atmosphere." [97]

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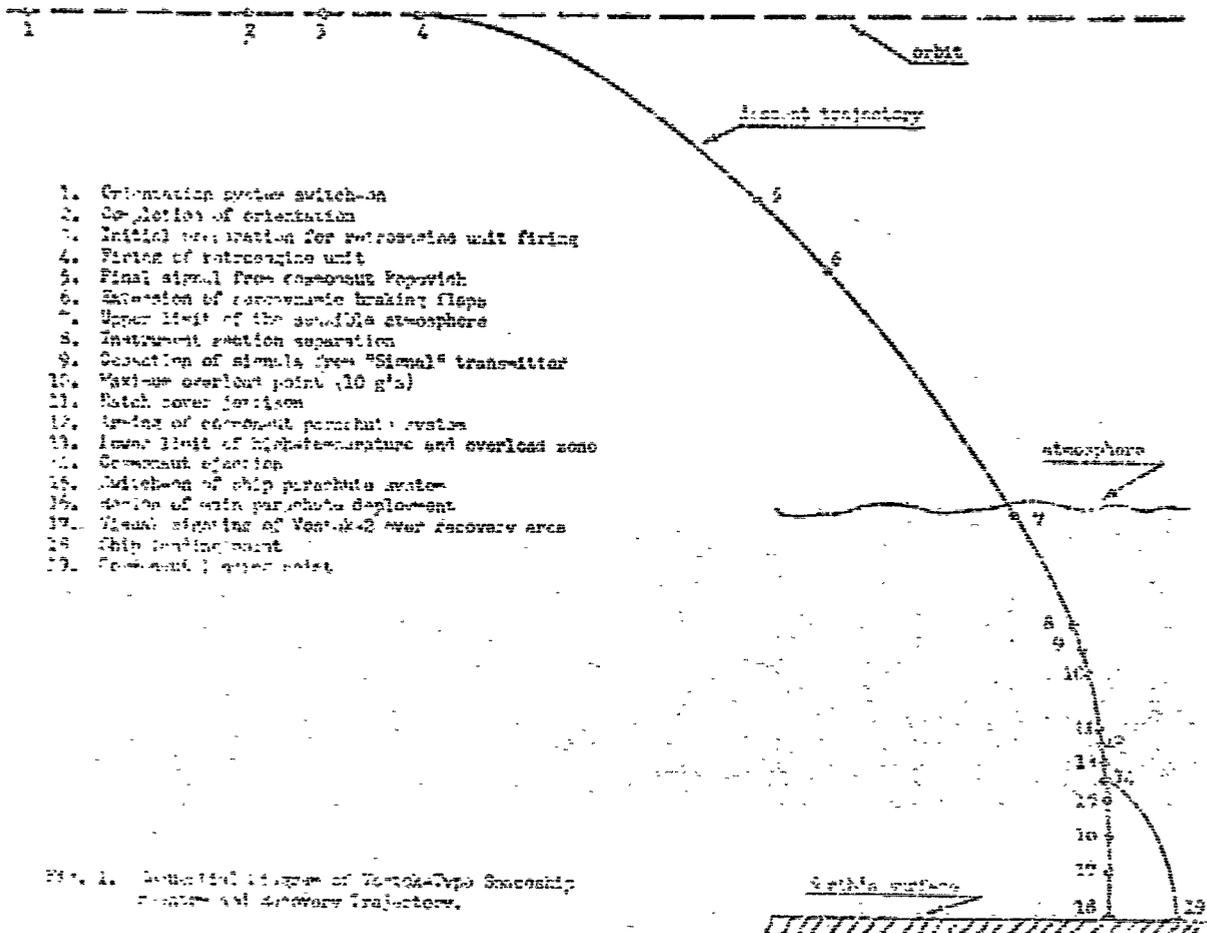


Fig. 1. Ballistic stages of Vostok-type spaceship descent and recovery trajectory.

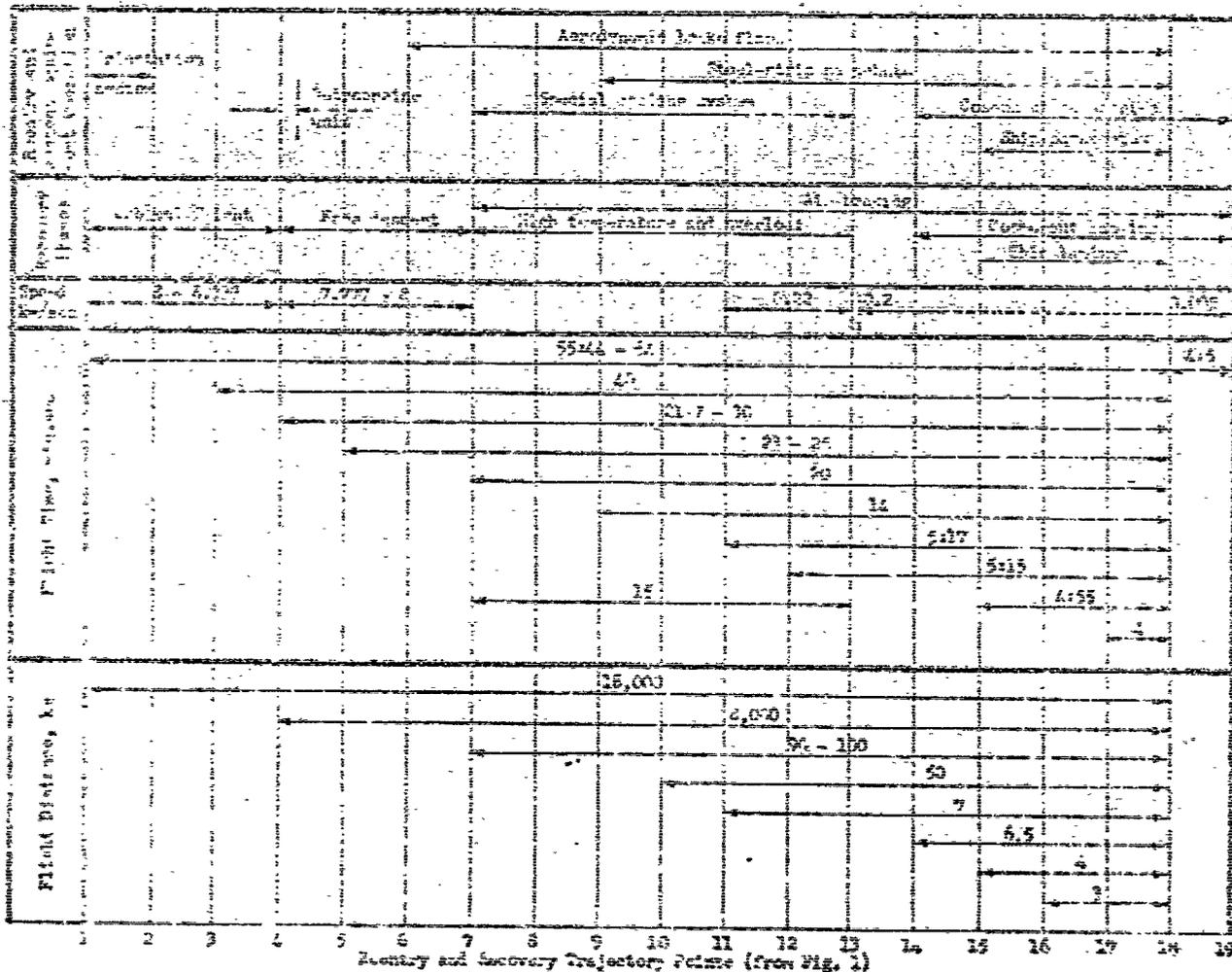


Fig. 2. Reentry and Recovery Sequence Data for Vostok-type Spaceships.

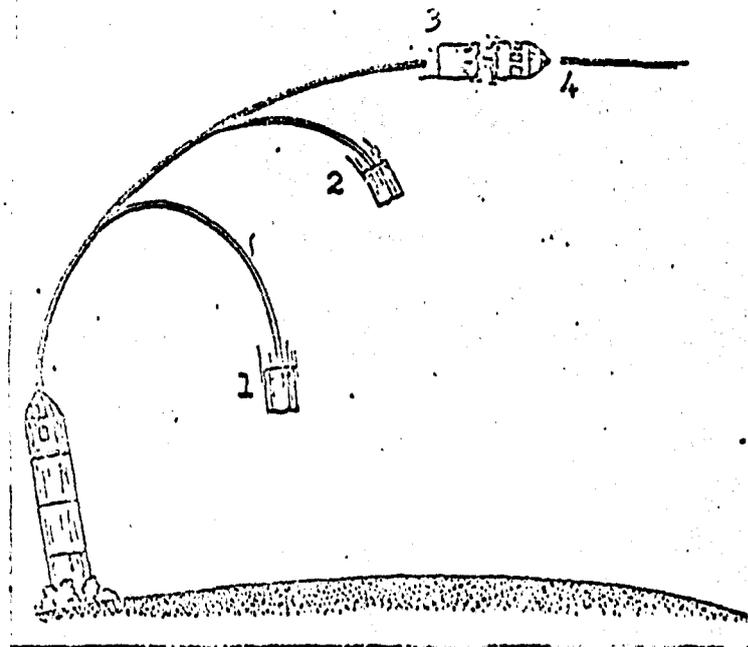


Fig. 3. Powered Flight Path of Vostoks 1 and 2.

1. First-stage separation; 2. Second-stage separation; 3. Last-stage separation; 4. Beginning of free-flight path.

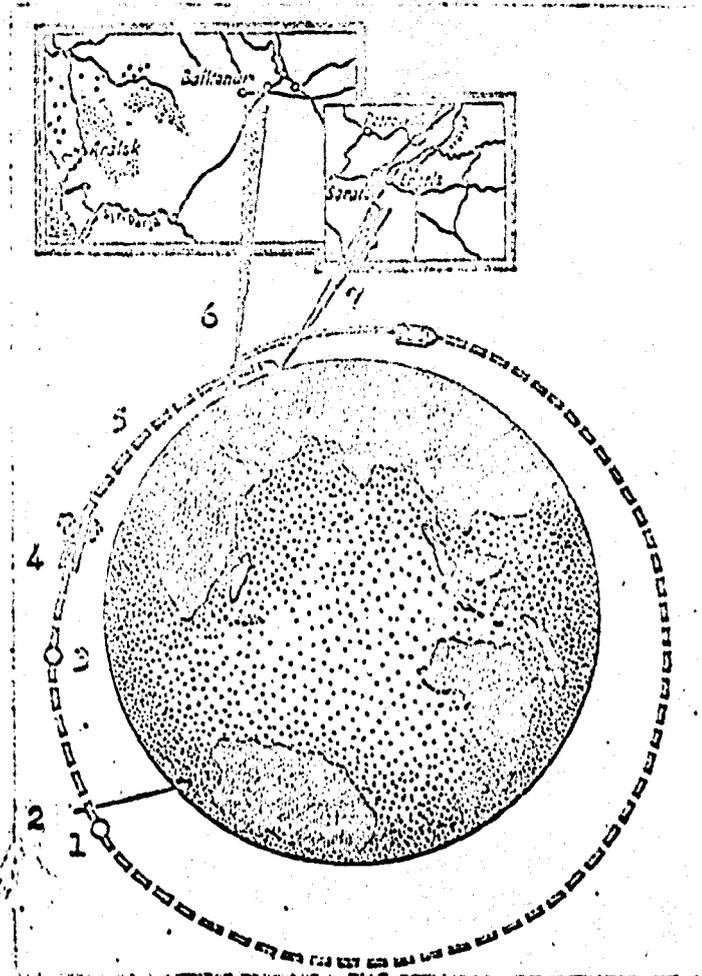


Fig. 4. Earth Orbit of the Vostok. Launch and Recovery Areas for Vostoks 1 and 2 (Moscow Time).

1. 9:51 Automatic orientation system switched on; 2. 9:52 Over Cape Horn; 3. 10:15 Retrofire ready signal; 4. 10:25 Retro-engines switched on; 5. 10:35 Spacecraft enters the dense layers of the atmosphere; 6. Launch area; 7. Recovery area.

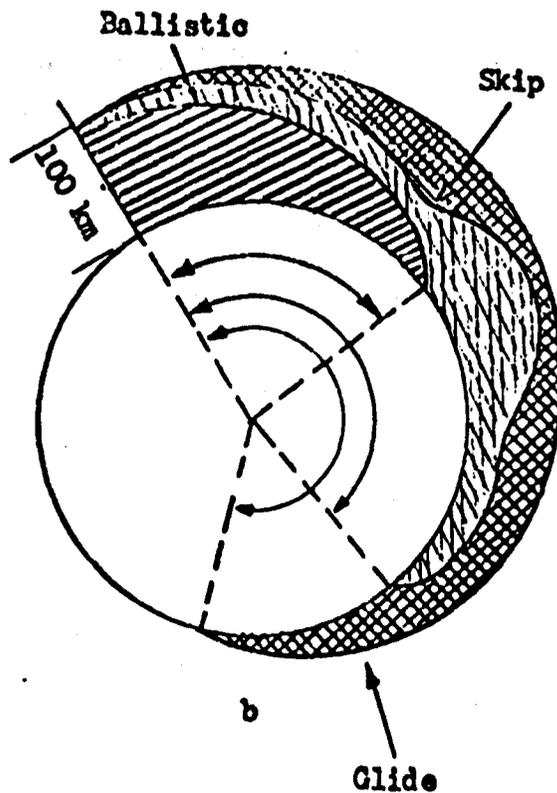
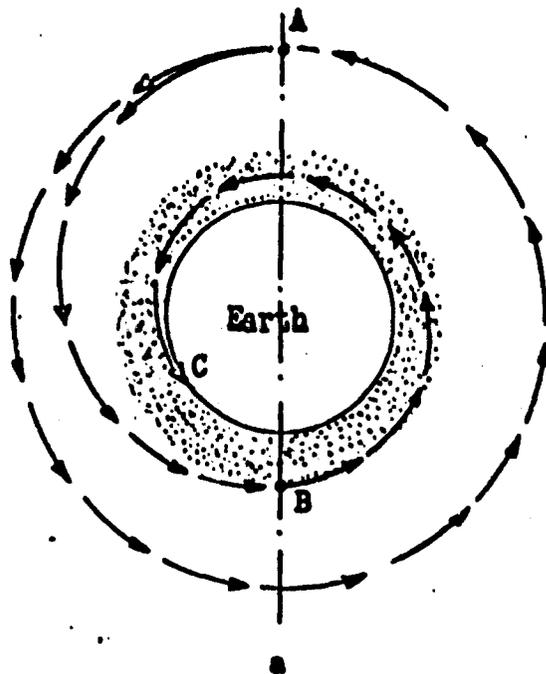


Fig. 5. Deceleration methods

a - Spaceship's trajectory in return to Earth (points B and C are arbitrary); b - methods by which a spaceship can return to Earth from an altitude of 100 km: the ballistic way is shortest; the glide is longest.

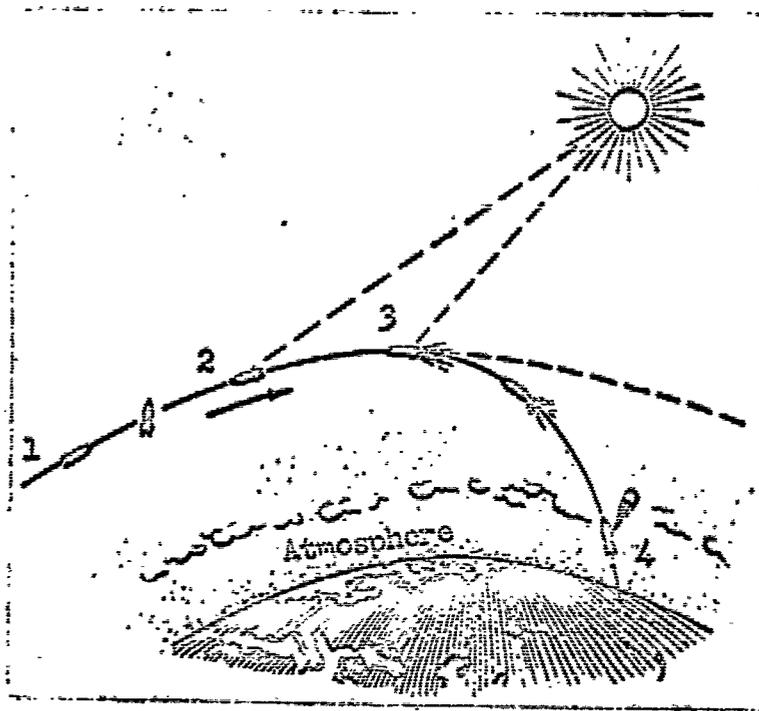


Fig. 6. Approximate Sequence in Spacecraft Reentry

1. Orbital flight; 2. Orientation on the Sun; 3. Retroengines switched on; 4. Descent of the spacecraft.

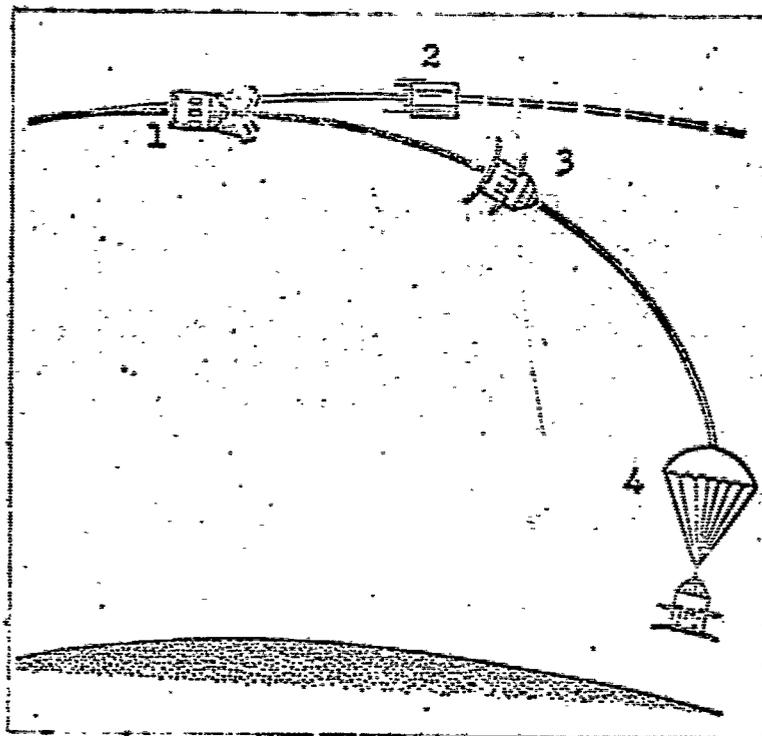


Fig. 7. Reentry Trajectory for Vostoks 1 and 2.

1. Retroengines switched on; 2. Last stage continues in orbit; 3. Aerodynamic deceleration flaps extended; 4. Parachute descent of the spacecraft.

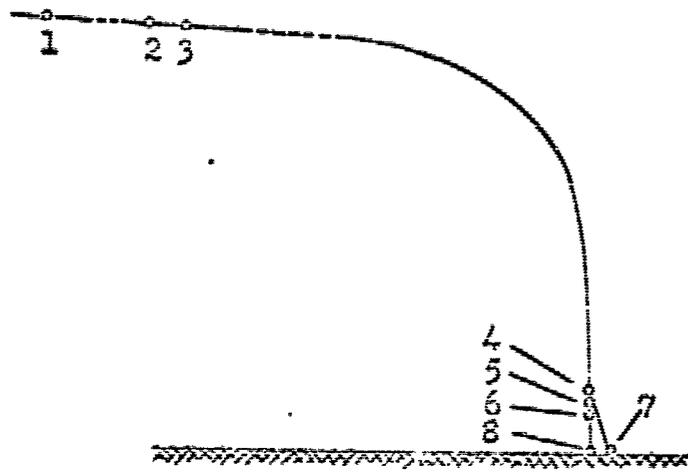


Fig. 8. Recovery Sequence for Spacecraft and Cosmonaut.

1 - Orientation system switched on; 2 - Orientation completed; 3 - Retroengine unit fired; 4 - Hatch cover jettisoned (altitude 7000 m, speed 220 m/sec); 5 - Cosmonaut ejected (altitude 6500 m, speed 220 m/sec); 6 - Automatic landing system switched on (altitude 4000 m, speed 220 m/sec); 7 - Cosmonaut landing point; 8 - Spacecraft landing point.

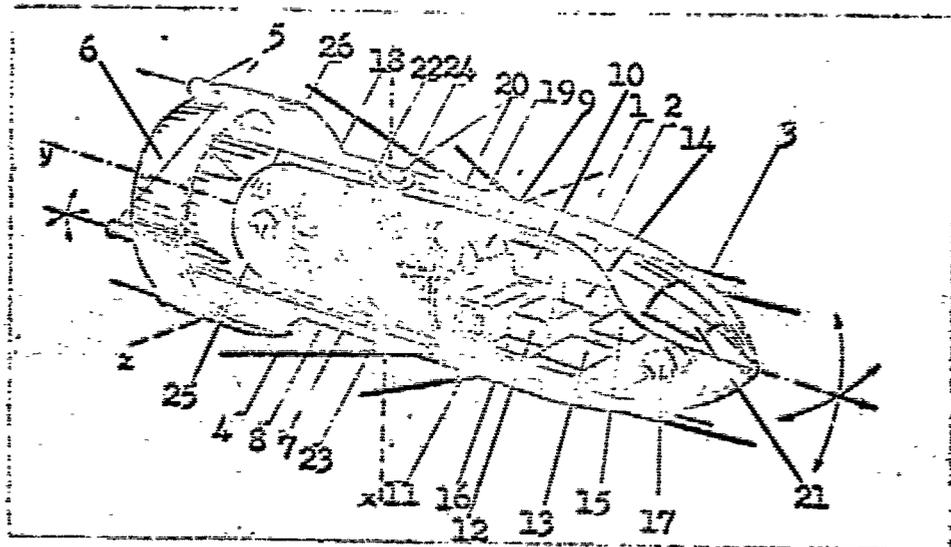


Fig. 9. The Vostok-type Spaceship

1 - highly polished surface (silicone coating); 2 - protective shielding; 3 - telescopic antenna; 4 - programmed guidance antenna; 5 - attitude jets; 6 - stabilizing ring; 7 - sliding couch for the cosmonaut; 8 - explosive charge for ejection; 9 - control instruments; 10 - "Signal" transmitter; 11 - recording apparatus; 12 - command attitude devices; 13 - command transmitter; 14 - reserve transmitter; 15 - reserve command transmitter; 16 - electric power source; 17 - inert gas supply; 18 and 19 - protective partitions; 20 - ports; 21 - parachute hatch; 22 - seat parachute; 23 - control panel; 24 - food supplies; 25 - supply of liquid oxygen; 26 - environmental control apparatus and fuel supply for retro jets.

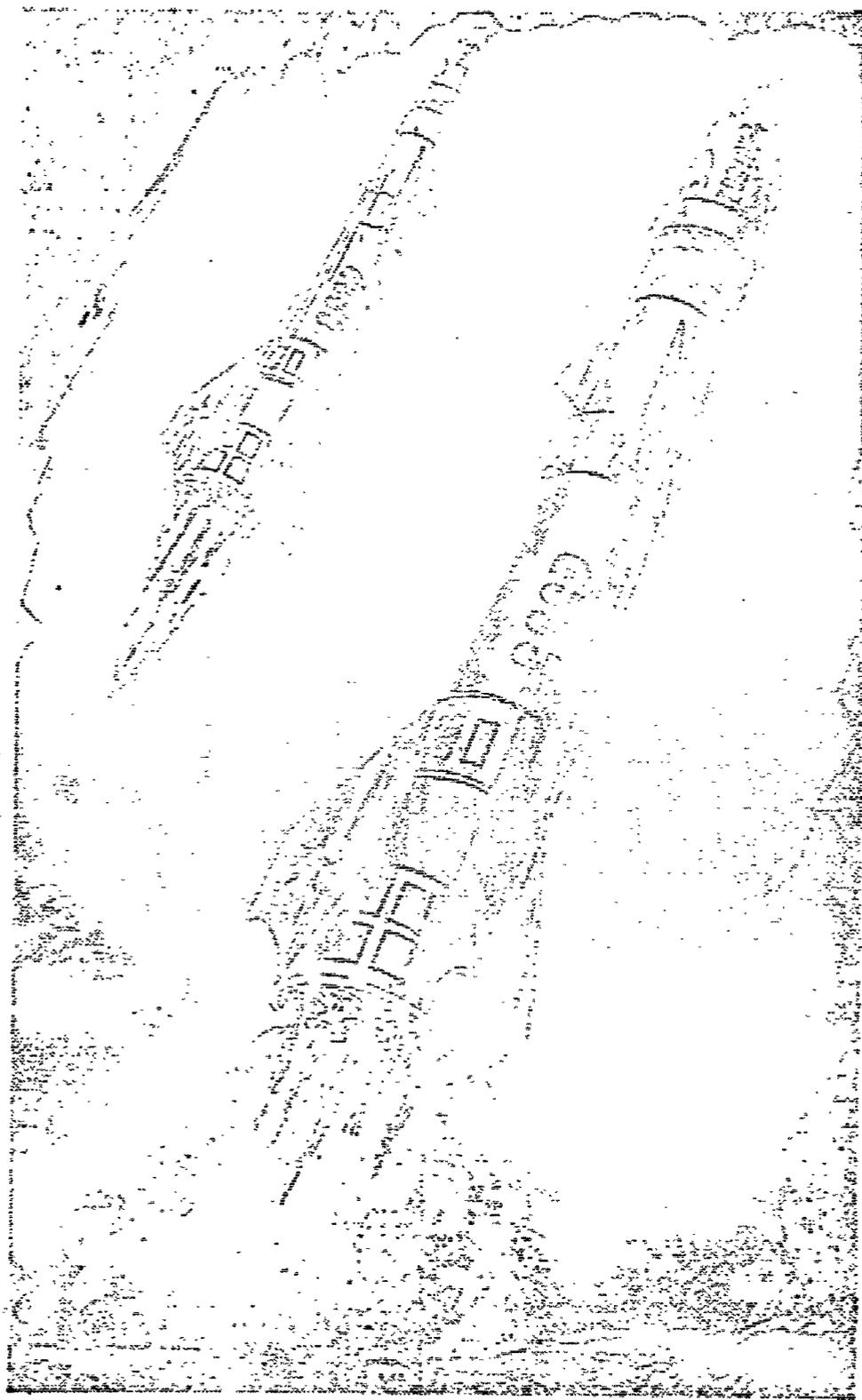


Fig. 10. Group Flight of the Vostok-3 and Vostok-4 (From a drawing by an individual who participated in the launching of these ships).

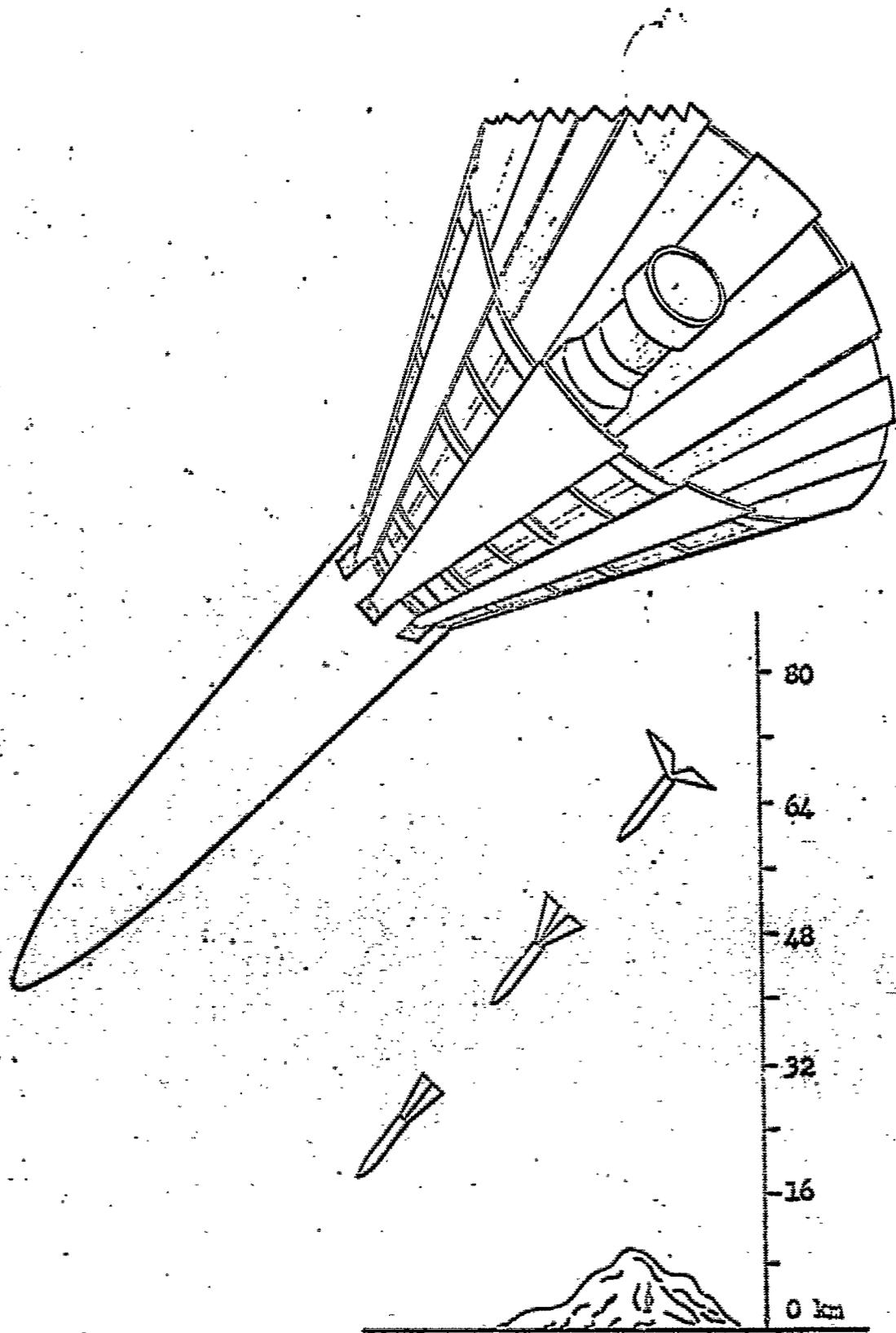


Fig. 11. Deceleration of Rocket by a Metallic Skirt

Fig. 12. Spaceship Wing

I - cross section of wing before reentry of the spaceship into the atmosphere; 1 - design elements; 2 - coating of thermal insulation, asbestos, or quartz; 3 - sublimating material; II - cross section of wing after landing of the ship.

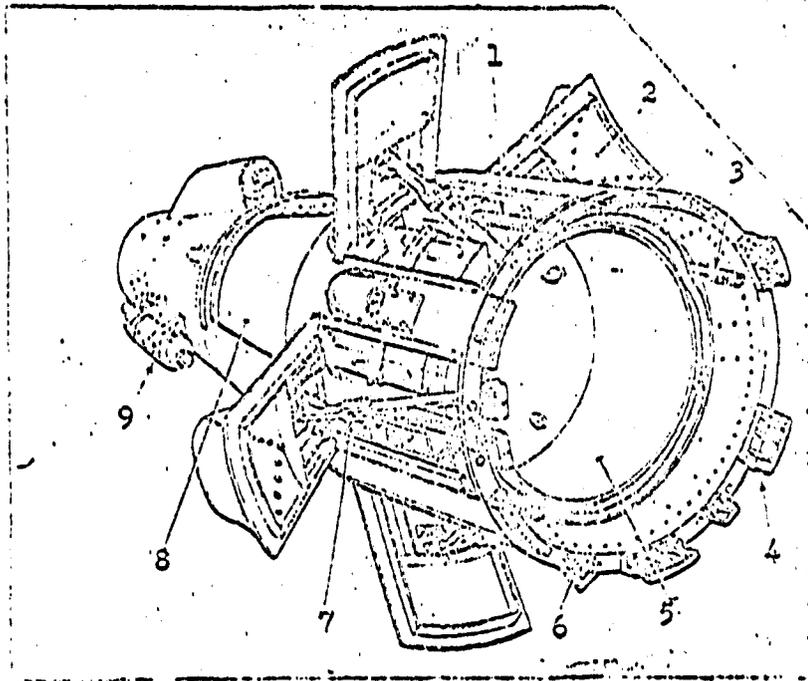
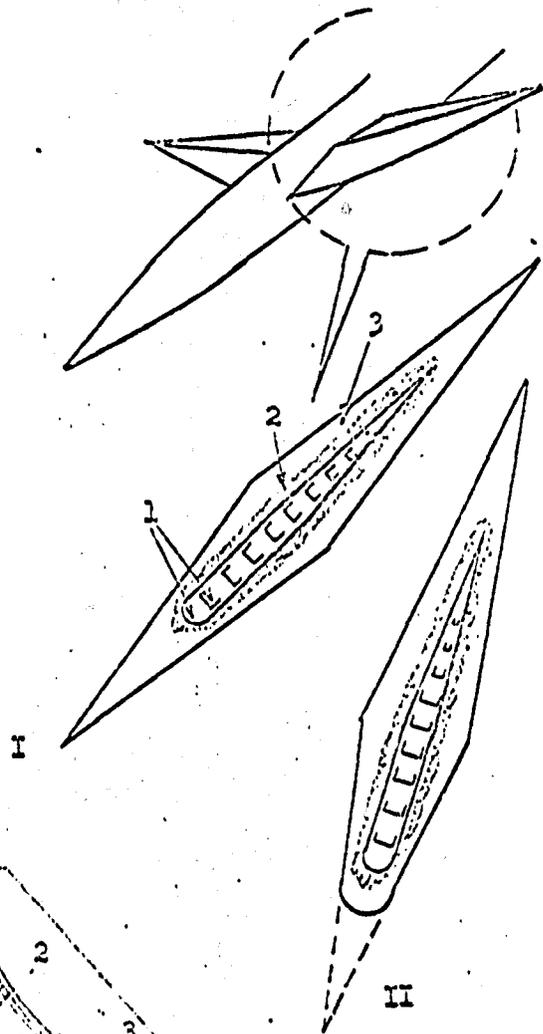
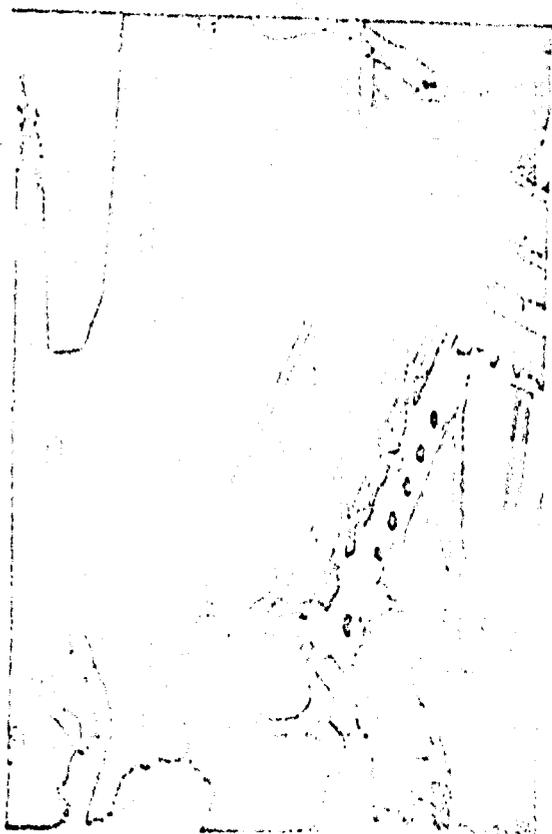
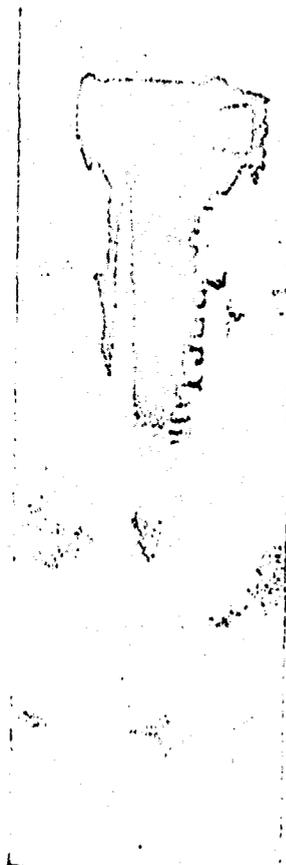


Fig. 13. Recoverable Nose Cone of Soviet Research Rocket.

1 - brake extension spring; 2 - brake; 3 - guidance mechanism terminal  
4 - joining lug; 5 - parachute compartment; 6 - electric terminals;  
7 - brake lever; 8 - instrument container; 9 - camera.

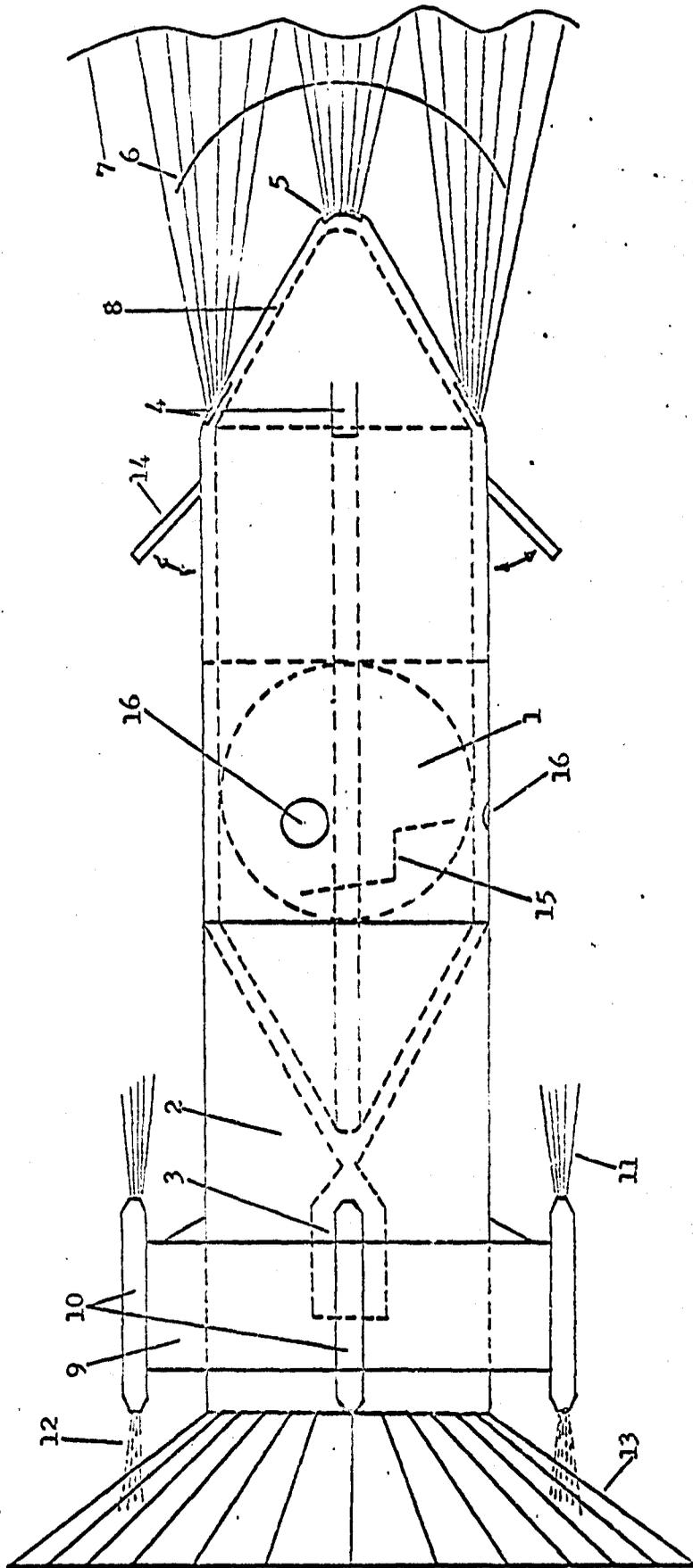


a. Cosmonaut bids farewell from the elevator at the launching pad.



b. Vostok spaceship.

Fig. 14. Spaceship Vostok Flight.



- |   |                                      |
|---|--------------------------------------|
| 1. Cabin section                          | 10. Attitude-control nozzle chambers |
| 2. Instrument section                     | 11. Gas flow during reentry          |
| 3. Retroengine unit                       | 12. Gas flow during orbital flight   |
| 4 and 5. Retroengine nozzles              | 13. Steel-strip parachute            |
| 6. Original shock wave                    | 14. Aerodynamic brake flaps          |
| 7. Shock wave produced by nozzles 4 and 5 | 15. Cosmonaut seat                   |
| 8. Porous cooling jacket                  | 16. Portholes                        |
| 9. Stabilizing ring                       |                                      |

Fig. 15. Possible Design Principles Used in Vostok Reentry Systems.

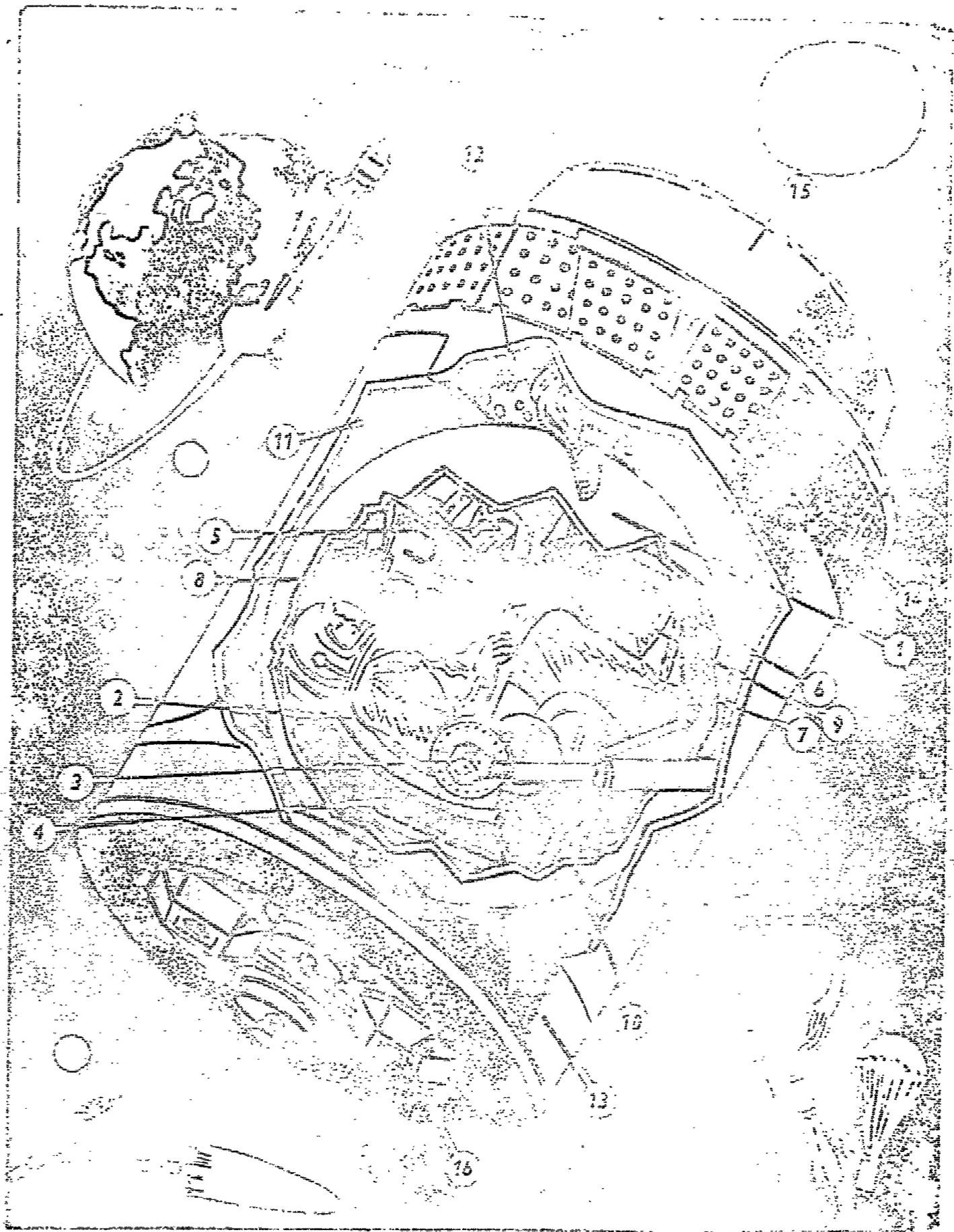


Fig. 16. First Man in Space. A Simplified Drawing of a Space Capsule Weighing 4725 kg

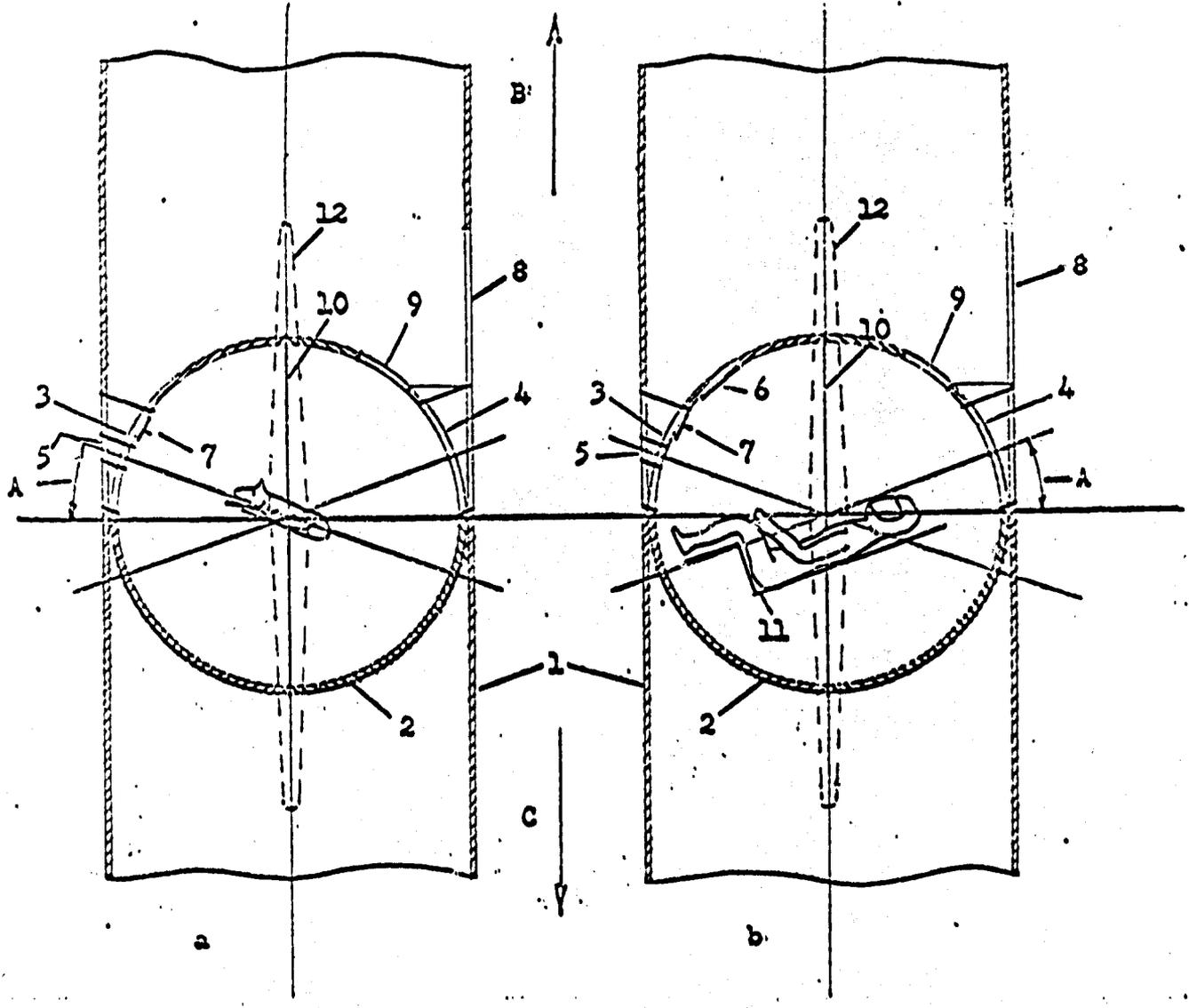


Fig. 17. Possible Shape and Location of the Cabin in Soviet Spaceships.

a - Cabin of second ship-satellite; b - cabin of Vostok; 1 - external housing of ship; 2 - spherical cabin; 3 - fast-opening hatch with porthole; 4 - fast-opening hatch; 5 - porthole with optical orientation device; 6 - instrument panel with globe; 7 - television camera; 8 - door; 9 - hatch; 10 - parting line of cabin; 11 - pilot seat; 12 - ablating wing; A - Angle between the lengthwise axis of the container (a) or the pilot seat (b) and the floor (cross-section) of the cabin; B - Launching direction; C - reentry direction.

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