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AVIATION ON THE THRESHOLD OF SPACE
(CHAPTER 9)

by

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13. ABSTRACT

Document discusses general problems and progress thus far involving space-aircraft or "lifting bodies". All sources quoted are from U.S. publications except for one French reference to a space station. Vehicles described include the "Dyna Soar", X-15, SV-5D, X-24A, HL-10, and a U.S. orbital space station. Problems discussed include heat-shielding, methods of control, speeds, and power sources.

Details of illustrations in this document may be better studied on microfiche

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CHAPTER 9

AVIATION ON THE THRESHOLD OF SPACE

The title of this book is most appropriate. The author did not choose it by accident. The fact is that the natural development of contemporary high-speed aviation performing flights into the stratosphere, is aerospace aviation. And if we take the prospects for the development of aviation, then apparently, that time is not too far off when the flights of flight vehicles in space will become commonplace.

Outer space can be arbitrarily divided into terrestrial space, near, and distant space.

Terrestrial space is usually considered as the zone surrounding the earth within limits of altitudes of 60-160 km. The experimental flights of the X-15 experimental aircraft and other vehicles in terrestrial space show that only special vehicles can fly in it. For maneuvering, they can to a certain extent use the aerodynamic controls. This fact has an important value because maneuvering with the aid of the gas-dynamic (jet) control which operates on chemical fuel, requires, as has been confirmed by flights on experimental aircraft, great fuel consumption.

Near space is considered as the zone within limits of altitudes of 160-480 km. In this zone the safety of manned flights is ensured with the use of comparatively simple biological protection. Scientists assume that at altitudes up to 500 km it is possible to use piloted flight vehicles which possess a speed corresponding to Mach number M = 25 (25 times the speed of sound), a flying range of several millions of kilometers and a duration of several months.

Distant space is space up to an altitude corresponding to twice the distance between the earth and the moon, i.e., up to 800,000-900,000 km. Utilization of distant space, as many scientists assume, to its whole depth will become possible only after the construction of bases on the moon and the mastery of the flights which permit maintaining reliable communications with these bases.

Space flight vehicles are subdivided, depending on the character and trajectory of their flight, into orbital pilotless vehicles of the type of artificial earth satellites, orbiting space stations with a crew aboard, and suborbital vehicles. Finally, the space flight vehicles include vehicles intended for a flight around the moon and landing on it, interplanetary vehicles and vehicles which rotate on orbits around planets (Fig. 132).

In this chapter we will briefly examine basically suborbital space vehicles more "related" to contemporary aircraft which accomplish flights into the stratosphere. These vehicles can go into orbit and can accomplish gliding flight in the upper layers of the atmosphere.

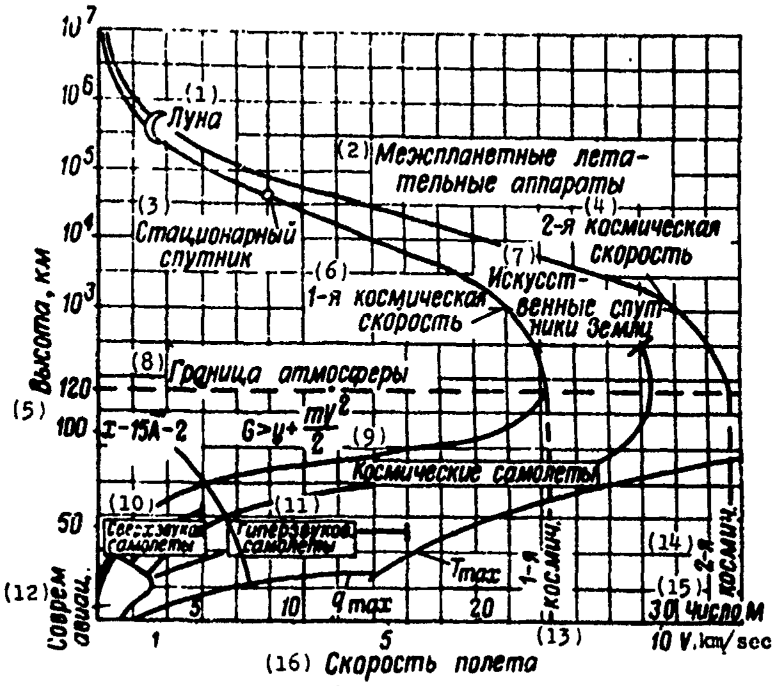

Fig. 132. Contemporary state of the mechanics of flight.

KEY: (1) Moon; (2) Interplanetary flight vehicles; (3) Stationary satellite; (4) 2nd cosmic velocity; (5) Altitude; (6) 1st cosmic velocity; (7) Artificial earth satellites; (8) Limit of the atmosphere; (9) Space aircraft; (10) Supersonic aircraft; (11) Hypersonic aircraft; (12) Modern aviation; (13) 1st cosmic; (14) 2nd cosmic; (15) M number; (16) Flight speed.

Thus far, only experimental vehicles of this form have been created to investigate the problems which appear in hypersonic flights, their return to the earth, control of them, etc. There are several proposed projects of such vehicles. It is impossible to describe comprehensively the existing experimental vehicles and the proposed suborbital vehicles. The author, in this case has set a goal – only to generally introduce the reader to suborbital vehicles and the problems which appear in the implementation of flights in them.

The most complex problem in flights of space vehicles is, perhaps, providing for their landing on the earth. As is known, the problem of landing a space vehicle on the earth consists in the necessity for guaranteeing the descent of a vehicle which possesses high energy, into the dense layers of the atmosphere and landing with defined accuracy on a given point of the globe while observing the limitations imposed by the structural strength and by the materials from which the vehicle is made, and also by the endurance of the crew. In order to effect a soft landing of the vehicle, it is necessary that the reserve of kinetic and potential energy which it possesses be gradually and completely expended at the end of the flight. For this, it is advantageous to use aerodynamic braking on landing. A return with the utilization of aerodynamic braking can be broken down into return with the utilization of lift and return without the utilization of lift (the so-called "ballistic reentry" into the atmosphere).

All ballistic vehicles accomplish their descent to earth without the utilization of lift. A ballistic descent involves a number of disadvantages. In the first place, since in the sector of reentry to the atmosphere the vehicle is not controlled, therefore the selection of the point of its landing on the earth is limited. The length of the trajectory of reentry of the vehicle into the atmosphere is great, and in the presence of the effects of disturbances, it may land hundreds of kilometers away from the desired landing place. As a result of this, rescue of the vehicle becomes a difficult, prolonged, and expensive operation. In the second place, during return from orbit, the landing can be made only at the point arranged in the orbital plane. Thirdly, even during the return from orbit of an earth satellite, the vehicle underwent the effect of a rather severe overload.

The disadvantages mentioned are eliminated when using the lift of the vehicle for effecting maneuver in a vertical plane during entry into the atmosphere (Fig. 133).

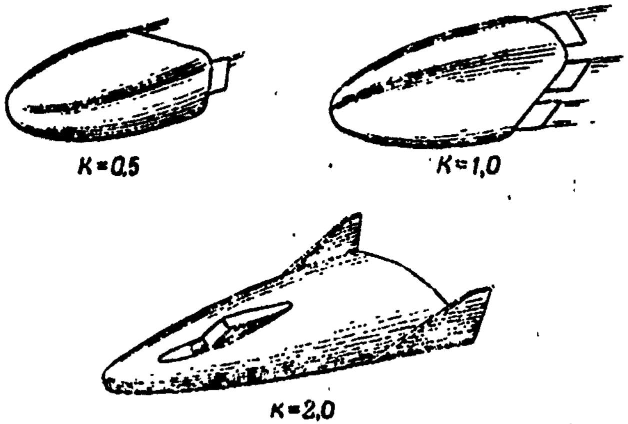

Fig. 133. Shape of vehicles which possess lift.

In the landing of space flight vehicles which possess aerodynamic characteristics, the area of touchdown must of necessity lie in the orbital plane. Furthermore, such vehicles are provided with a precise landing spot at least twice in twenty-four hours. There is yet another advantage in the utilization of such vehicles. Whereas during a ballistic descent of vehicles the magnitude of retro impulse must be very accurately maintained, but in the landing of vehicles which possess aerodynamic characteristics, the requirements for accuracy of the impluse are reduced and the conditions for the entry of the vehicle into the atmosphere may not be so strict.

Aerodynamic characteristics are important basically for providing maneuverability with respect to the plane of initial orbit. Actually, in order to accomplish a landing at a given point an exit from the orbital plane may be needed for the purpose of providing the assigned lateral flying range of the vehicle.

The problem of providing longitudinal range can be solved by selection of the time of imparting the retro impulse for the descent of the vehicle from orbit.

Thus, the major advantage of a vehicle which possesses aerodynamic characteristics at hypersonic flight speeds calculated for entry into the atmosphere, consists in its considerably greater maneuvering abilities as compared with ballistic vehicles. Such a vehicle, using maneuver in respect to pitching and banking, can accomplish a landing from orbit of satellite on any given airfield on the globe. An interplanetary vehicle with high aerodynamic characteristics can accomplish direct entry into the atmosphere and a landing on the earth, by maintaining the trajectory of entry by aerodynamic forces. It must be noted that direct entry into the atmosphere at hypersonic speed of a vehicle on a ballistic trajectory is impossible in practice due to the small width of the entry corridor into the atmosphere and the great thermal loads.

In the American press it is announced that vehicles of the "Apollo" type with a low value of hypersonic lift-drag ratio (less than 0.5) can ensure a range of flight of about 2000 km with lateral departure from the initial orbital plane not exceeding 100-200 km. Vehicles of the SV-5 type with a mean value of lift-drag ratio (from 1 to 2) ensure a flight range of more than 5500 km and lateral departure from the orbital plane of 650-1500 km. Vehicles with a high value of lift-drag ratio (from 2 to 3) have a flight range of 15,000-17,000 km and lateral departure from the orbital plane of 1800-5500 km.

The great flight ranges and lateral departure from the orbital plane of vehicles with a high value of aerodynamic characteristics considerably expand circle of problems being solved. But with an increase in the aerodynamic characteristics the solution to the problem of providing for the stabilization of the flight vehicle is severely complicated.

The completion of a flight of a space vehicle is a safe landing on the surface of the earth. This problem is reduced to the solution of the problems of protection of the vehicle from aerodynamic heating, overloads, control over the time of reaching the earth and the location of the landing place.

A flight vehicle descending from the orbit of an artificial satellite of the earth possesses a great reserve of energy.[1] It is made up of the kinetic energy conditioned by the speed of the vehicle and the potential energy conditioned by the position of the vehicle relative to the surface of the earth. Upon entry into the dense layers of the atmosphere, a shock wave appears in front of the nose of the vehicle, which heats the air to a very high temperature. As the flight vehicle enters the lower lying denser layers of the atmosphere it is heated all the more, and its speed continuously decreases as a result of aerodynamic braking. In so doing the kinetic energy of the vehicle is converted into heat. If all the energy of the vehicle, converted into heat, was liberated inside it, then this quantity of heat would be more than sufficient for the complete evaporation of the vehicle with all its contents. However, in actuality a significant quantity of heat is removed into the space surrounding the vehicle as a result of the action of strong shock waves and heat radiation from the heated surface of the vehicle. Heat transfer by the shock waves is the result of the

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[1] This pertains in even greater measure to a vehicle which approaches the earth from outer space.

interaction of the molecules of gas surrounding the flight vehicle. The intermediate layer of gas compressed to a high pressure and heated to a high temperature, in which there occurs the process of particle interaction and their contact with the flying body, is limited from the front by the pressure front. The shock wave moves far away into the atmosphere in all directions from the vehicle, and in it remains the wide wake formed by the heated gas, in which there is included the greater part of the heat which is liberated in the flight of the vehicle in the atmosphere. The heat flow which reaches the surface of the vehicle comes from the compressed layer of gas, mainly because of friction.

The strongest shock waves appear when the cone of flight vehicle is blunted. Since part of the heat going out into the space surrounding the vehicle is directly proportional to the intensity of the shock wave, then the stronger it is, the smaller will be the quantity of heat transmitted to the vehicle as a result of friction. Because of this, for space vehicles which land on the earth, blunted forms are considered more preferable than the extended stream-lined shapes which are classic in contemporary aerodynamics.

Extraction of the heat which reaches the surface of the flight vehicle is accomplished by absorption of the entire heat by the skin material or by means of the use of a heatproof (ablation) coating.

With the removal of the entire heat entering the body by the material of the skin of the vehicle, the thickness of the shielding layer of the material which absorbs heat is selected as that with which the skin temperature is limited to that permissible value for the selected material.

In the case of a ballistic descent in the atmosphere or entry into the atmosphere with large slope angles of trajectory, the vehicle rapidly reaches the lower, denser layers of the atmosphere. During this short interval its braking is accomplished. In so doing, a large quantity of heat is formed. However, since the time of braking is short, the complete quantity of heat transmitted to the vehicle during braking may prove to be comparatively small. In this case, it is possible to use a vehicle with a strongly blunted nose part and a sufficiently thick heatproof coating which possesses great heat absorption. With a mildly sloping entry into the atmosphere of a vehicle which possesses lift, more time is required to reach the denser layers of the atmosphere. In this case, the braking of the vehicle is accomplished basically at very high altitudes. Since at such altitutes the density of the atmosphere is low, the heat flow applied to the vehicle will also be small. This heat flow, in the final analysis, may be equal with the heat flow being emitted by the surface of the vehicle. In this case, it is possible to use a method of heat dispersion with the aid of the radiation cooling of the surface of the vehicle coated with a thin metallic skin.

In the opinion of the scientists, the simplest solution for the protection of the vehicle against aerodynamic heat is the utilization of a heatproof coating which consists of heat-insulating layers of glass fiber and other materials similar to it. As a result of the intense heating, the skin of such coating is melted and vaporized. The vaporized material retards the heat transfer from the shock wave to the vehicle.

The solution to the problem of reduction in the overloads which appear during the landing of space vehicles, in certain cases, can be a more difficult problem than the protection of the vehicle from aerodynamic heating. In order to keep the overloads within limits permissible for man, it is necessary to use vehicles which possess lift. Lift, by decreasing the vertical speed of descent, increases the flight path of the vehicle to the earth and thus decreases the maximum overload.

Let us point out, that prior to entry into the atmosphere of the earth, the motion of a space vehicle in the coast phase of the trajectory obeys the laws of celestial mechanics. This means that the vehicle moves only under the action of inertia and gravitational forces. However, in the atmosphere aerodynamic forces act on the vehicle, which change its motion. The force of attraction is always directed to the center of the earth. The aerodynamic drag force acts opposite to the direction of motion of the vehicle. Centrifugal and lift forces act at right angles to the direction of motion of the vehicle. The dynamics of the motion of the vehicle in the entry phase to the atmosphere is determined by its inherent inertia and resulting forces anumerated above. The aerodynamic drag force reduces the speed of the vehicle, while the centrifugal and lift forces impart acceleration to it in the direction perpendicular to the direction of its motion. These aerodynamic forces, just as the accelerations caused by them, change in direct proportion to the atmospheric density and to the square of the speed of the vehicle.

With the immersion of the vehicle into the atmosphere its density rapidly increases. As a result of the increasing drag, the speed of the vehicle begins to diminish. Thus, overload is proportional to the product of two values, one of which – density – increases, and the other – speed – decreases. At first, the overload which acts on the vehicle increases. However, at a certain point in the trajectory, the deceleration of the vehicle begins to predominate over the increase in density. This gives rise to the fact that overload reaches a certain peak value, whereupon it begins to decrease.

It should be noted that a serious problem in the return of a space vehicle to earth is considered to be the provision for the accuracy of control which makes it possible to fulfill a predetermined program of descent, avoiding excessively high overloads and aerodynamic heating!

Flight on a geocentric orbit does not impose heavy demands on the accuracy of guidance on entry into the atmosphere, since a too steep an entry can be easily corrected with the aid of a short term application of thrust, and in the event of a too mildly sloping entry, the vehicle can be given a retro impulse. But, with entry of a vehicle into the atmosphere with a speed which exceeds orbital velocity [first cosmic] the vectoring errors are extremely dangerous. An excessively steep entry can lead to the destruction of the vehicle during descent, too flat – to its irretrievable drift into outer space. If, as a result of vectoring error, the lower limit of the entry corridor is breached, the vehicle will enter the atmosphere at an inadmissibly large angle, thereby undergoing the action of too great overloads. If vectoring error leads to breaching of the upper limit of the corridor, then the vehicle will not be able to submerge into the sufficiently dense layers of the atmosphere and to counteract its speed with a single immersion into the atmosphere. The entry corridor, within the limits of which the landing of space vehicles is possible, is very narrow.

In the foreign press, a great deal of attention is given to methods of control of the reentry trajectory of the vehicles into the dense layers of the atmosphere. Two methods are mentioned: control of reentry using nominal trajectory and control with prediction of the reentry trajectory.

With control of reentry to the atmosphere with the utilization of nominal trajectory, overload, speed, and altitudes are first calculated for the design conditions of reentry and are introduced into the storage device of a computer. During the descent of the vehicle in the atmosphere, with the aid of sensors, deviations of these parameters from their nominal values which are stored in the storage device of computer are determined. The mismatch signals are used either for stabilization of the selected nominal trajectory, or for the production of a new trajectory leading into the assigned area. As nominal trajectory, as a rule, the trajectory is used, which satisfies the limitations in respect to thermal condition and overloads.

They assume that the maneuvering capabilities of the vehicle can be used most fully in control with trajectory prediction of reentry depending on the current parameters of the trajectory. In this case, controllability is preserved with more significant deflections of the actual conditions of entry from the calculated than in control with utilization of nominal trajectory.

In one of the foreign journals, a method of control of the entry trajectory of the vehicle into the atmosphere is proposed in which the requirements of controllability and safety of flight are combined. We are speaking of control of the entry trajectory according to the rate of change the surface temperature of the vehicle. This method of control is promising.

It must be noted that the range of flight speeds of hypersonic vehicles is very great. It encompasses landing, subsonic, transonic, supersonic, hypersonic and orbital speeds. Flight takes place at altitudes from sea level to several hundreds of kilometers above the surface of the earth. The limits of change in the angle of attack of a hypersonic vehicle are considerably wider than in conventional aircraft. In the whole range of M numbers, ram effects and angle of attack of the vehicle should be stable, completely controllable and acceptable for piloting. In certain words of foreign specialists, it is pointed out that regardless of the shape and dimensions of the hypersonic flight vehicle, during flight at speeds corresponding to M numbers $M = 10$ or $M = 20$, the development of completely new control systems will be required. This is explained by the fact that a hypersonic flight vehicle possesses practically no aerodynamic damping. Such an aircraft will accomplish undamped harmonic oscillations relative to the condition of equilibrium of the amount of static stability being determined. Therefore it is necessary to use artificial damping.

Research conducted abroad has shown that ensuring the stability of an aerospace vehicle is connected with satisfying the inconsistent requirements conditioned by the complex dependence of the aerodynamic characteristics of the aircraft upon M number and angles of attack. At hypersonic speeds and large angles of attack, a fin in the upper location is most effective, however its utilization gives rise to an increase in aerodynamic heating. A compromise solution may be the utilization of a fin of with negative angle of incidence spaced at the wing tips.

Control of an aerospace vehicle in connection with the great range of speeds, altitudes, and flight ranges is a very complex problem. In foreign literature an example taken from the practice of the flights of the American vehicle "Dyna Soar" is given. The orbital winged vehicle "Dyna Soar" (Fig. 134) is intended for flight in the atmosphere and beyond its limits and must have a maximum speed in orbit of approximately 28,000 km/hour with a minimum speed not exceeding the normal landing speed of conventional aircraft. It is pointed out that in the flight of this vehicle to an assigned distance it is necessary to very accurately maintain the calculated trajectory, a significant part of which takes place in a vacuum. Deflections from trajectory in the phase from entry into the atmosphere to the damping of excess speed are especially strictly limited. Here the limits of deflections form the so-called safety corridor, the flight inside of which eliminates the possibility of the emergence of critical values of aerodynamic heating and overloads. At the initial stage of the development of the "Dyna Soar" vehicle it was assumed that control of its flight would be completely automatic. Then it was considered necessary to allow for the possibility of piloting the vehicle by the pilot on board, in so doing, preserving the devices necessary for provision for automatic flight.

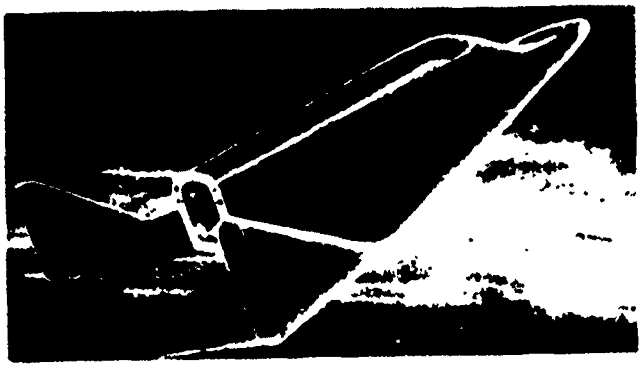

Fig. 134. Orbital winged vehicle "Dyna Soar."

In the uncommonly wide range of flight conditions of aerospace aircraft, conventional aerodynamic guidance is not in a position to guarantee the satisfactory stability characteristics and controllability mainly due to the reduction in the effectiveness of the control surfaces as the flight altitude increases; in airless space, the control surfaces become entirely useless. Control at all altitudes can be provided for by addition of jet control to the aerodynamic guidance necessary for low-altitude flights. Jet guidance, as is known, can be accomplished with the aid of jet nozzles, gas vanes, and rotation of the jet engine.

The jet nozzles are installed on the vehicle in such a way as to ensure control relative to the three principal axes of the vehicle. By changing the flow rate of the gas being fed into the nozzle, it is possible to change the amount of jet power, and therefore, the value of moment which causes the aircraft to turn. The gas vanes are made in the form of movable plates which are arranged in the flow of the exhausts of the jet engine. Gas vanes are widely used in contemporary rocket technology.

In foreign literature, it is noted that the most promising is the method of controlling the vehicle with the aid of jet nozzles which can work on the products of the decomposition of hydrogen peroxide.[1]

In using exhaust thrust for control of a flight vehicle and its stabilization considerably greater energy consumption is required than in aerodynamic control. Therefore, the problem of preserving the effectiveness of aerodynamic control to the highest possible altitudes of flight is considered very urgent. Apart from the selection of the special shape of the vehicle and the increase in the dimensions of the control surfaces, the installation of fins on the ends of the delta wing contributes to preserving the effectiveness of aerodynamic control. Another means of increasing the effectiveness of aerodynamic control at high altitudes consists in the utilization of boundary layer control. The aviation specialists assume that this method makes it possible to shift the boundary of the effectiveness of the usual aerodynamic control to high altitudes. The effectiveness of the ailerons can be increased in the following manner. Compressed air, bled from the last stage of the compressor

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[1] Control with the aid of jet nozzles working on hydrogen peroxide was carried out on the "Dyna Soar" vehicle.

of the turbojet engine [TRD] (ТРД) is fed to the proportional flow control valve regulated by a hydraulic booster from a knob in the cabin of the aircraft. When, for example, the pilot moves the knob to the right, the valve directs compressed air towards the nozzles arranged along the span over the upper surfaces of the lowered left aileron; to the nozzles of the raised right the air inlet remains closed. As a result, there is a considerable increase in the rolling moment (as a result of the increase in the lift of the lowered aileron and the increase in the effective arm of this force). An increase in the control effectiveness of the altitude and direction control can be made in similar manner. In recent years, American aviation specialists suggested several self-adjusting control systems. One of these systems was tested on the experimental X-15 aircraft (several flights were conducted with it).

On the X-15 plane research was conducted on landing as one of the problems which must be solved in the creation of a hypersonic vehicle, is the problem of landing a vehicle without an engine and with low aerodynamic characteristics. Permissible vertical speeds for series jet fighters are considered to be 3-4.5 m/s, that is an order less than is typical for X-15 vertical speeds (30 m/s). All this forced the development of a special procedure for execution of a landing. The landing consists of the section of approach to the strip, the section of flareout of trajectory, on which with the aid of a normal overload the high vertical speed of the aircraft is dissipated, and the section of braking prior to the moment of touchdown. In the last section, the pilot maintains an overload approximately equal to one. The basic section in landing is the section of flareout of trajectory, on which the pilot creates maximum available overload. Its magnitude is restricted both by aerodynamic factors and by the conditions of strength of the landing gear. In connection with the fact that the lowering of the landing gear leads to a substantial impairment of the landing conditions, it is advantageous to accomplish it the end of the leveling section.

The X-15 aircraft was created in the USA to study the problems of hypersonic flight and reentry into the atmosphere. Its wing was sweptback, the wing span was 6.82 m. Rated speed was equal to 7200 km/hour, and the flight altitude 76 km. On it there was installed a liquid propellant rocket engine [ZhRD] (ЖРД) with a thrust of 26,100 kg. The launching weight of the aircraft with a complete supply of fuel was 15 tons, and after consumption of the fuel, approximately 7 tons. The launching of this vehicle is accomplished from a B-52 aircraft.

A series of research flights was conducted on the X-15 aircraft during which it withstood temperatures up to 650°C. Not all flights ended successfully. The foreign press reported that two of the first models of this aircraft suffered accidents on landing (for instance, on one the landing gear and some other units were broken).

In November 1967 during the 191st flight, a catastrophe struck the third model of the X-15 aircraft. It is necessary to note the following. In the official announcement about the catastrophe of this aircraft, it is said that the radar and telemetering data relayed from the aircraft to the ground in its descent to an altitude of 18,300 m show that in the period of reentry to the atmosphere the overload exceeded that permissible for the structure of the plane. It is further pointed out that it was unknown whether the cause of the catastrophe was the breaking of the structure or whether failure of the aircraft occurred after loss of control in descending from an altitude of 79,600 m.

It must be noted that after the achieving maximum height, in one of the last instructions transmitted to the pilot, was that the angle of descent of the plane was too great, and soon the pilot relayed that the aircraft had gone into a spin. It is also unknown whether the pilot was prevented from leaving the aircraft because of the impossibility of ejecting as a result of the heavy overloads or because of structural failure.

At the present time this aircraft is scheduled to be replaced by an improved version. The design of the new X-15 aircraft calls for the installation on it of a delta wing (Figs. 135, 136) with the angle of sweepback along the leading edge of 76° and an area of 56 m^2. The span of the wing remains as before – 6.82 m. Designed to "withstand" high thermal loads, the delta wing will be made as a unit with the fuselage tank. The chord ratio of the delta wing is approximately 3%. On its tips fins will be placed to improve the directional stability of the aircraft under all flights conditions. Longitudinal and lateral control of the aircraft will be accomplished by elevons.

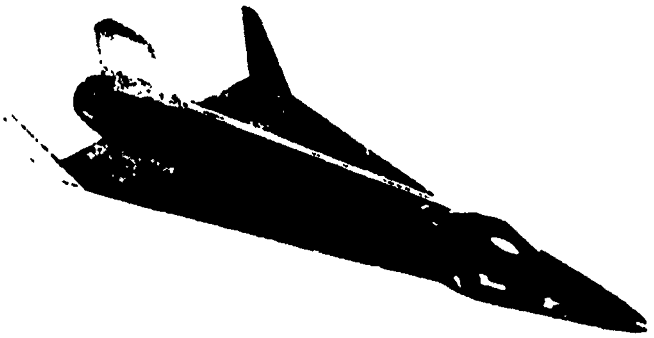


Fig. 135. Experimental hypersonic X-15 aircraft with delta wing.

The vehicle is designed for a ram effect of 10,750 kgf/m^2, a speed corresponding to M number $M = 8$, and overloads: normal ±4.25, longitudinal ±3 and lateral ±1.

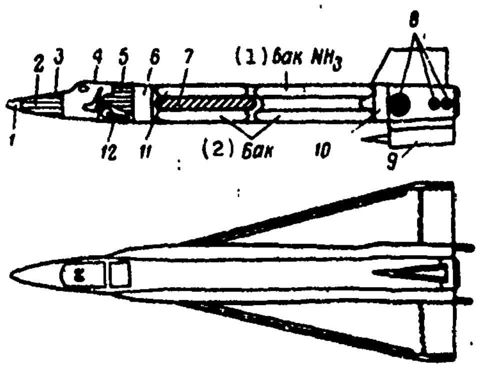


Fig. 136. Composite diagram of the X-15 experimental hypersonic aircraft with delta wing: 1 – adjustable or fixed nose; 2, 5 – equipment compartment; 3 – cone; 4 – cockpit; 6 – booster power plant compartment; 7 – reservoir for creating pressure in the fuel tanks; 8 – fuel pumps; 9 – ramjet engine [PVRD] (ПВРД); 10 – compartment with scientific instruments; 11 – liquid oxygen tank; 12 – nose wheel landing gear.

KEY: (1) NH_3 tank; (2) tank.

The possibility is being examined of installing a more powerful ZhRD on the aircraft having a thrust of up to 45,000 kgf, and also a PVRD (under the fuselage).

The launch weight of the aircraft should not exceed 24,500 kg.

In foreign literature it is indicated that in the construction of this aircraft it is proposed to use heat-resistant materials instead of an ablation coating, a reinforced heatproof coating of the cockpit, aircraft control to be accomplished with the aid of an inertial navigational system in a complex with a special high-speed computer and the self-adjusting flight control system. The storage device of this system will store a large quantity of data in regard to aerodynamic parameters, the values of altitude and distance to the landing areas, the critical values of heating of the leading edge of the wing, pressure and overloads. System will furnish complete information on air navigation and aircraft control (about the angle of attack, bank, ram effect overloads, flight path angle, true altitude above the earth, etc.).

The improved X-15 aircraft is calculated for a flying speed corresponding to M number M = 8. It is expected that its flight tests can solve the problems connected with the performance of flights at a speed of 1800-2400 m/s over long distances.

The launching of this aircraft, as before, will be accomplished from a B-52 aircraft.

Today in the USA and the other capitalist countries very wide research work is being conducted in creating hypersonic space vehicles with a lifting body. In the foreign press it is pointed out that this is one of most promising trends in the development of aerospace technology. The advantages of a vehicle with a lifting body are small overloads on entry into the atmosphere, good maneuvering capabilities, a low ratio of surface dimensions to volume, moderate requirements for heat shielding, stability of flight at hypersonic speeds and, finally, the ability to accomplish an aircraft-type landing.

In one American journal the question is examined of the selection of minimum value of the lift-drag ratio of the vehicle with which it can land on a runway. It is noted that a landing like an aircraft is possible beginning with a lift-drag ratio equal to 2.5. At one of the flight centers of the USA, a landing of a modernized version of an F-104 aircraft was accomplished with a maximum value of lift-drag ratio of less than 0.8 with power-off. The pilot who made the landing stated that this was very hazardous and unreliable. It is assumed that the pilot of an aerospace vehicle will experience severe fatigue during the performance of the mission and, therefore, for sure performance of the landing in this case the lift-drag ratio must be equal to 4 and perhaps higher may be required. In so doing, switching on of the rocket engine for a short time at the landing stage is not eliminated.

Lifting body vehicles, according to the opinion of foreign specialists, can be used for solving problems of reconnaissance and inspection, as research and rescue space vehicles, and vehicles for material and technical support and supply of future orbiting space stations, and subsequently – for making piloted interplanetary flights. A number of aerospace firms of the USA are now investigating all the problems which appear during the creation of vehicles with lift, including those with lifting body. For example, the possibility is being studied a vehicle with lifting body making an accurate landing utilizing maneuver on entry to the atmosphere, etc. Studies are being conducted with the aid of a pilotless SV-5D space vehicle with lifting body. Its weight is approximately 4000 kg. The launchings of the vehicle are accomplished with the aid of a carrier rocket, its flight lasts 30 min, aerodynamic efficiency at subsonic speeds reaches 4.5, at hypersonic speeds – 1.2-1.4 (at a rated speed of entry into the atmosphere of about 8000 m/s from an altitude of 128-165 km). Heatproof coating in burning did not change the aerodynamic form of the vehicle and rigidity of the construction. The thickness of the heat shield of the fuselage varies along the body of the vehicle from 70 to 20 mm. The heat shield ensures a temperature of the aluminium skin of the vehicle lower than calculated at an external surface temperature of 1650°C.

The first SV-5D vehicle was launched 21 December 1966, was sent to the assigned altitude, and completed a successful flight. It entered the dense layers of the atmosphere on a trajectory close to that calculated and then approached the landing area. After an unsuccessful attempt at interception in the air, the vehicle sank in the ocean. On 5 March 1967 the launching of the second SV-5D vehicle was realized. The vehicle completed the flight but in its final phase could not be intercepted, and it sank. On 19 April 1967, a third vehicle was launched which was intercepted in the final flight phase and saved. According to reports in the foreign press, in the flight of this vehicle a study was made of the range of speeds from hypersonic on entry into the atmosphere to speeds corresponding to M number M = 2.

The program of the creation of aerospace vehicles in the USA calls for the development of a piloted vehicle with lifting body. It is proposed to use it for regular flights into space, which in the opinion of foreign aviation specialists, eliminates the necessity for creating complex launching systems of using a one-time carrier rocket. The first such piloted vehicle in the USA should be the X-24A vehicle (Fig. 137) which consist of an aerodynamic body of triangular form in a plane with a convex upper and less convex lower surface and a blunt, almost spherical nose part. The stability of the vehicle and control of it are ensured with the aid of three fins with rudders, two elevons in the upper part of the body and two flaps in its tail. In case of ineffectiveness of the control airfoils on entry into the atmosphere, provision is made on the vehicle for using a gas-dynamic control system. It consists of jet vanes which operate on a liquid nitrogen similar to the ones that are used in VTOL aircraft. The gross weight of the vehicle is approximately 5000 kg. The fuel load is 2270 kg. The lift-drag ratio at subsonic speed is 4.6, at hypersonic – 1.1-1.4. On the vehicle there is an ejection seat which ensures the escape of the pilot from the cockpit at any flying speed and at any altitude. As compared with vehicles of other configurations, the X-24A has higher volume utilization factor, i.e., a greater value of the ratio of internal volume for the accomodation of payload to the area of the external surface of the vehicle.

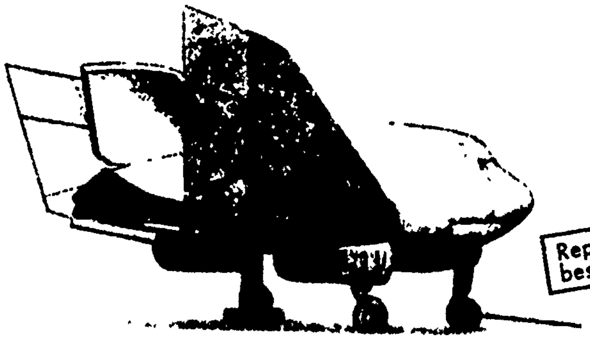


Fig. 137. X-24A experimental vehicle with lifting body.

It is proposed to accomplish 20-30 launchings of the X-24A vehicle. Its first tests will be made without an engine. The vehicle will be suspended from the wing of a B-52 bomber and will be separated from it at an altitude of 12-15 km at a speed of more than 800 km/hour and then accomplish a glide descent with a landing. During subsequent tests, the vehicle will be equipped with a rocket engine having a thrust of 3630 kg and which will be switched on after separation of the vehicle from the B-52 aircraft. It is assumed that the vehicle with this engine will achieve an altitude of 30 km at a speed corresponding to M number M = 2, whereupon it will accomplish flight under gliding conditions.

For training pilots in the control of this space vehicle at low speeds and on landing, a special training vehicle has been created, which in arangement, construction, and dimensions is identical to the space vehicle. Its weight is 4.5 t. On it, a turbojet engine with small thrust has been installed. The engine is located in the tail part of the fuselage, the air intake – under the fuselage. The vehicle is provided with the usual retractable landing gear. On the training vehicle, takeoff and climb are accomplished just as on conventional aircraft with the aid of a turbojet engine. Then the engine is cut off and the vehicle accomplishes a glide landing.

In the American press it is indicated that in the USA several more experimental piloted space vehicles with lifting body were built. One of them has the form of semicone; its weight with pilot is equal to 500 kg. A vehicle of tubular construction with a laminar plywood skin is provided with light tricycle gear with a steerable nose wheel. Rudders installed on a double vertical fin, and also elevons mounted at the outboard side of the fin serve as the controls. A solid-propellant booster rocket engine which develops a thrust of approximately 100 kg has been installed on the vehicle. This engine can be used emergency cases for reduction of the landing speed and an increase in maneuvering. Vehicle tests were conducted. It was carried aloft by a two plane to an altitude of up to 4.5 km where it was disengaged and put into a gliding condition with a speed ∿220 km/hour. Its free flight lasted about 3 min. Subsequently a vehicle of the same form was constructed, but with greater weight. Its flight tests are scheduled for three years. In the maiden flight on this vehicle, the pilot disengaged it from the tow plane at an altitude of about 14 km and piloted the vehicle, completing series of maneuvers; it made two turns of 90° each, simulated a landing approach, then from altitude 3.6 km – braking to reduce vertical speed to 3 m/s. Speed in level flight in this case was reduced to 970 km/hour.

A flight apparatus of the second type, on which a glide flight was also made has the form of semicone with a blunt nose part, with vertical and horizontal control surfaces. The tests on this apparatus are scheduled for three years.

Aviation specialists are also working on the creation an aerospace (orbital) aircraft mainly for the delivery of loads to an orbiting space station. In foreign literature is given a number of plans for such aircraft are provided. Let us examine some of them briefly.

According to one of the plans the aerospace vehicle is a two-stage aircraft with three engines installed in the first stage, and one engine placed in the second stage. The aircraft must take off with the aid of a catapult or carrier aircraft. As fuel for the engines, it is proposed to use liquid hydrogen and oxygen. The launching weight of the aircraft is 150 t. After separation of the first stage, it returns to earth. The second stage reaches the assigned orbit in which the crew performs the mission assigned to it: to meet with the orbiting station, and deliver the cargo, cosmonauts, etc., to it. Then it returns to earth.

Another plan calls for the construction of a three-stage aerospace aircraft. The first and third stages of the aircraft – piloted, the second stage – pilotless; it is intended for putting the third stage into orbit. The propulsion system of the first stage consists of six ramjet engines (three engines under each wing cantilever). The second and third stages are attached over the fuselage of the first stage and are arranged, according to the diagram, in tandem. The third stage has a variable sweep wing (Fig. 138). It "opens" in the process of landing upon entry into the atmosphere. For vertical landing, the third stage is provided with lift engines. A model of this aircraft was demonstrated at the 1967 Air Show in Paris.

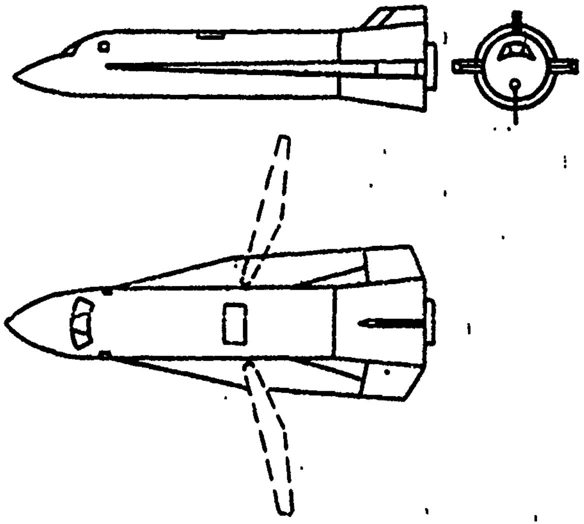


Fig. 138. Diagram of an orbital vehicle.

Another interesting project is the aerospace aircraft intended for transporting cargo weighing 3 tons to a station moving in orbit at an altitude of about 300 km. The aircraft consists of two stages. The second stage is intended for the delivery of a payload into orbit and to provide for the return of the aircraft into the dense layers of the atmosphere. It is provided with six rocket engines which work on liquid oxygen and hydrogen. The first stage of the aircraft climbs to approximately 35 km and develops a speed corresponding to M number M = 7. After separation of the seond stage it returns to a designated airfield. The second stage meets with the orbital station, having first completed the necessary maneuvers. The pilot, using the high aerodynamic characteristics of the second stage, has the capability to determine the descent trajectory, taking into account the conditions of aerodynamic heating and to select (in a rather wide range) an airfield for landing.

In one of the foreign journals a French plan for a space aircraft has been published. The aircraft is two-stage. Its launching weight is equal to 150-230 t.

The propulsion system of the first stage is compound and consists of a jet engine [VRD] (ВРД) and a ZhRD. The VRD works up to a flight speed corresponding to M number M = 4.5. The ZhRD is switched on at M number M = 4.

The plan calls for two versions of this aircraft. In the first version, the aircraft having a launching weight of 230 t, consists of two return stages (Fig. 139). In the second version, the aircraft having a launching weight of 150 t, consists of two return stages and a non-returning booster.

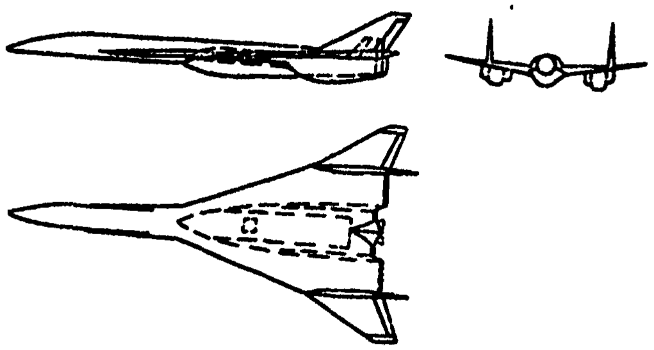


Fig. 139. Diagram of an aerospace aircraft with two return stages (launching weight 230 t).

The first stage has a low-aspect wing without a tail unit and the landing gear is of the conventional type. Under the wing, combined turbofan-ramjet engines are installed. The fuel tanks are located in the wing (kerosene) and in the fuselage (hydrogen in the forward compartment). The second stage (the orbital vehicle) has in the forward section a pressurized cabin for a two-man crew. The cabin can be made in the form of detachable capsule (at a cost of an increase in the gross weight of the vehicle). Behind the cabin, there are tanks with oxygen and hydrogen, the payload section, auxiliary tanks, and then the engines. The vehicle has a low-aspect wing creating a lift-drag ratio somewhat greater than 1, which should provide satisfactory maneuverability in the return stage. For landing, variable geometry wing surfaces are used which create a lift-drag ratio on the order of 5 (just as in conventional aircraft). In the landing approach and landing stages a light booster TRD with its own fuel tank is used.

The booster introduced into the construction of the second version of the space aircraft makes it possible to substantially reduce the launching weight (by approximately 35%). The booster thrust (six turboram jets) amounts to 41 t, its weight is 31.8 t. The first stage of the vehicle weighs 107.2 t, the orbital vehicle – 11 t.

This space aircraft is intended for carrying out rescue operations, orbital injection at an altitude of 322 km of a payload weighing 8-10 t when using a system with a launching weight of 150 t, orbital flights, weather forcasts, and mapping of the earth's surface.

According to foreign press reports, one of the American firms is developing a plan for an aerospace aircraft with variable geometry, which during return to earth will use jet engines for maneuvering. The range of lateral maneuvering of this apparatus, equal to 5600 km, will be obtained by means of a combination of gliding with the achievement of average drag-lift ratio in hypersonic flight (from 1.7 to 2.3) with cruising flight in the atmosphere at subsonic speeds. The reduction in this range to 1300 km in implementing cargo operations will make it possible to increase the payload weight accomodated inside the vehicle at the expense of the fuel utilized in cruising flight.

This aircraft has a lift-drag ratio of 1.9 in hypersonic flight, an elongated body with almost parallel walls and a very elongated wing which is retracted into the fuselage between the lower ablation heat-shielding screen and the basic shell of the construction. In order to increase the stability of the vehicle under conditions of transonic flight the wing is partially extended, and under conditions of subsonic cruising flight – completely. The wing construction is designed for cruising flight. The wing has landing flaps. Directional stability of the aircraft is ensured by the dual fins, and control – by elevons and by the rudder. The flat lower heat shield can be completely removed for repair after return to the earth. To the upper surface of the main construction made from titanium, insulation has been applied which is protected by anti-radiation shielding panels made of a special alloy designed for repeated use.

The aircraft is equipped with two bypass engines which at hypersonic speed are drawn inside the fuselage, during gliding at subsonic speed they are extended simultaneously with the wing. Fuel for these engines is stored in the wing and fuselage. For purposes of maximum utilization of the lift capacity of the carrier rockets, loads are placed both in the vehicle itself and in the transition compartment between the vehicle and the carrier.

The range of lateral maneuvering of the vehicle in cruising flight can be increased by means of in-flight refueling, for which it is possible to use modern tanker-planes flying at a speed of 450-550 km/hour.

There are other plans for aerospace aircraft. Figure 140 shows a proposed aerospace aircraft with second stage orbital vehicle, and Fig. 141 – a two-stage aerospace aircraft. The first stage of this aircraft after uncoupling returns to base, the second stage is accelerated to orbital speed and delivers passengers and cargo to the destination point. Whereupon it also can be returned to the earth.

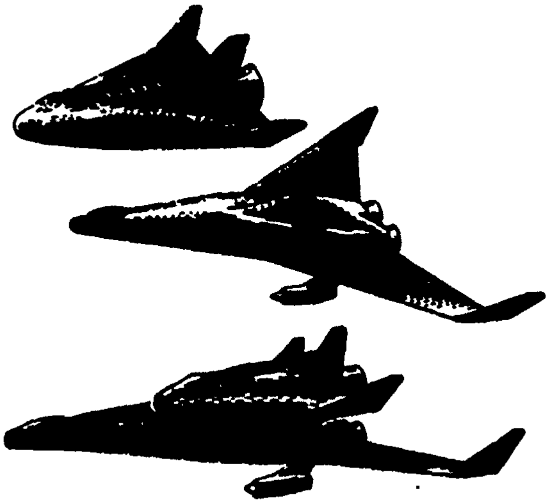
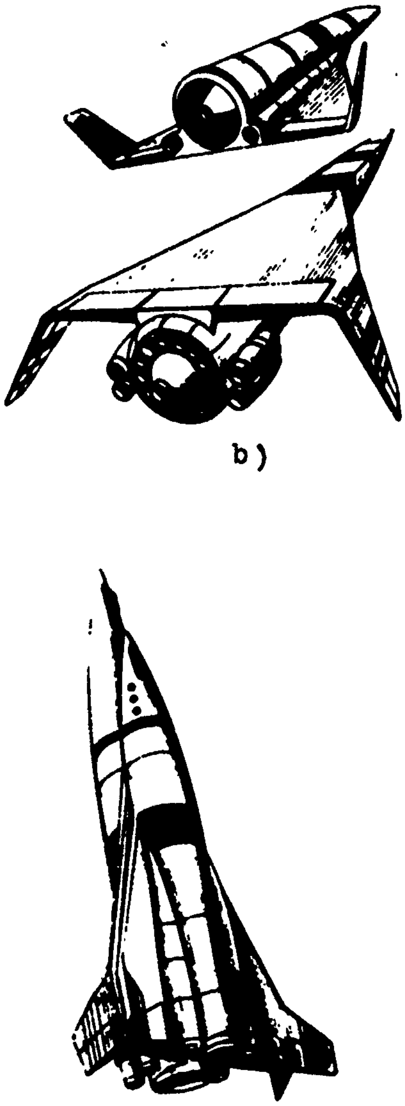


Fig. 140. Aerospace aircraft with two stages (a drawing).



b)

a)

Fig. 141. Aerospace aircraft with two stages (a drawing): a) the moment of starting; b) after stage separation.

A project has been developed for an aerospace vehicle in which it is proposed to use an HL-10 experimental vehicle. The booster stage of the aircraft (external module) consists of an HL-10 vehicle enlarged 5.5 times, and the orbital stage (internal module) -- a modified HL-10 vehicle.

There are also plans for aerospace vehicle with a delta wing.

In the foreign press it is indicated that the projects being developed today for aerospace vehicles are faced with these requirements: the total number of passengers and crew members should be 12 men, they must be able to be on board the aircraft without a pressure suit; the payload weight delivered into orbit should be not less than 23 t; the cargo compartments must be air-tight; the maximum value of overload – 3; the aircraft must have completely self-contained systems of navigation and control and to have a capability to accomplish a landing on instructions from the ground.

As the foreign specialists assume, the main problems when developing aerospace vehicle are: the creation of a ZhRD with great thrust which can stand more than 100 starts; provision for satisfactory aerodynamic characteristics over a wide range of altitudes and speeds; perfection of a mechanism for the separation of the stages (the modules); protection of the construction against aerodynamic heating.

As the powerplants of the aerospace vehicle it is proposed to use a ZhRD working on liquid oxygen and hydrogen. From three to nine such engines which develop thrust of 180 t each will be installed in the booster stage (the accelerator), and from two to three – in the orbital stage of the aircraft. It is also announced that a solid-propellant rocket engine [RDTT] (РДТТ) with a diameter of 6.6 m is being developed for utilization in the booster stage of the aerospace vehicle. Thus, the possibility has not been eliminated that the booster stage will be one-time. It is assumed that the functioning of all systems of the aerospace vehicle should proceed automatically from takeoff to landing, and the crew will only check on them during flight. In this way, at any moment the pilots can intervene in the operation of the systems and take control themselves.

Special attention is being paid to methods and facilities of display. A group of combined indicators which obtain information from an onboard computer will project the data in "compact" form necessary for monitoring the course of the flight.

Two American firms "Boeing" and "Lockheed" are developing a two-stage aerospace orbital vehicle with vertical launching. In the press these data are given: the booster stage has a length of 76 m, the wing span 50 m; the orbital stage – a length of 48 m, the wing span 25 m. The launching weight of the aircraft is about 1600 t.

The state of development of an orbital space station and an aerospace vehicle was discussed at a conference which was held in California in 1969 on the theme "Operations connected with the creation of a space station." In the reports of the specialists at this conference the problems of creation and operation of a 12-place orbital space system [OKS] (OHC) which will be subsequently converted by means of the gradual addition of modules into a 50-place space base were examined. The reports also discussed questions of the rational design of an OKS taking into account the changing weight requirements for delivery into orbit of the OKS itself and its separate elements, the assembling of equipment, and also problems and means of transferring crews and passengers from the aerospace vehicle into the OKS, the pumping over of liquids, the transloading of various equipment, etc. Conclusions were made regarding the necessity for the development of a simple universal docking mechanism and reliable mechanisms for the internal and external transloading of equipment from the aerospace vehicle to the OKS.

In addition, at the conference requirements were stated and substantiated for the power installations for the OKS, a space base and orbital spaceport on the assumption that after 1985 creation of an orbital complex with a crew of 100-150 men is possible.

The first power threshold to be overcomed in flights into space, is, as pointed out in the foreign press, circumterrestrial orbit, It can serve, as it were, as an intermediate station for the vehicles which leave for distant space. Circumterrestrial orbits can be used for the start of expeditions to the moon and other planets of the solar system. The purpose of other flights on circumterrestrial orbits may be missions connected only with the earth.

Outside of the dependence a space expedition on the final targets, an important factor will always be the efficiency of the system utilized for putting the vehicles into circumterrestrial orbit. This factor puts specific limitation on the implementation of any extraterrestrial expedition. Today, the cost of rocket systems for putting vehicles into space is still high because rocket systems after their one-time utilization are lost forever. However, a step forward can be made in the implementation of space flights by a more effective and more ideal means — with the aid of reusable aerospace systems. An aerospace system — this is a one-or the multistage autonomous piloted space flight vehicle, capable of going into circumterrestrial orbits, leaving its payload there and independently returning from orbit to its base — to an assigned point on earth. Such a vehicle can cope with circumterrestrial orbit and other missions. Similar vehicles in the future can "be developed" into a system capable of also accomplishing flights into distant space. Moreover, it is difficult to conceive of routine flights into outer space without the utilization of aerospace systems.

For the descent and landing of space flight vehicles on the earth, foreign specialists propose using a rotor device. In foreign literature, it is pointed out that with the aid of such a device it is possible to accomplish the necessary braking on the entire trajectory of the descent of a space vehicle, the stabilization of the vehicle, a glide descent with the utilization of aerodynamic characteristics, to change the drag of the flight vehicle over wide limits, to execute maneuvers in landing, and to ensure at the moment of contact with the earth, a speed close to zero. The change in the drag of the flight vehicle during descent can be made by a change in the conicity or stroke angle of the blades of the rotor, and lift - by a change in the angle of incidence of the plane of rotation of the rotor. The rotor device, as they assume, can be used for the descent of vehicles of any shape because the greater part of the lift will be created with the rotor itself and not by the vehicle.

This device consists of rotor and a system of controlling it. The rotor has several blades, with the aid of which under conditions of autorotation, braking of the flight vehicle and control of its descent path are effected. It is possible to assume that a rotor device being equipped with an engine can execute the functions of a rotor for maneuvering under conditions of landing. In this case a flight can be made between two points located any distance from one another or it can hover before landing.

In the foreign press, it is pointed out that the landing of space vehicles with the aid of a rotor device has significant advantages over the landing of ballistic vehicles which use parachute systems for descent in the atmosphere and also over the landing of vehicles with lift-drag ratio which is used for reducing lift. These advantages consist of the possibility of wide adjustment of the drag coefficient and the provision for the necessary overloads, and also the possibility of accomplishing a shock-free vertical landing on a previously determined landing area. It is said that the introduction of a rotor into the construction of a space vehicle will increase the weight of the latter by approximately 1%, according to preliminary computations.

The landing of a space vehicle on the earth with the aid of a rotor device will be accomplished in the following manner.

The rotor is extended at an altitude of about 90 km at a speed of 7.92 km/s, and then it spins under the action of the incoming flow. The ram effect of the flow in this case is equal to 9.76 kg/m^2. In the set mode of rotation of rotor, the vehicle goes into a gliding flight. The braking of the vehicle with the rotor is begun at an altitude of 76 km when overload is equal to 0.3, and the lift-drag ratio equals 1. The rotor creates lift and 50% of the total drag. During the greater part of period of braking, the flight vehicle accomplishes gliding up to the moment that its speed reaches values corresponding to M number $M = 4$. With further deceleration and in transonic flight, the rotor rotates at maximum permissible speed and accumulates the maximum amount of energy. As soon as the speed of the vehicle becomes subsonic, gliding is again renewed. During this time the rotor works as brake, preserving a high speed of rotation. The space vehicle in gliding is brought to the assigned landing place. In so doing, its speed decreases to a value which ensures a safe touchdown.

It must be noted that upon entry into the dense layers of the atmosphere, the surfaces of the rotor blade will undergo strong aerodynamic heating. With the location of the rotor behind the descending vehicle, the greatest thermal stresses will arise in the zone of the intersection of the shock waves which formed near the body of the descending vehicle and the blades of the rotor. In the case of the descent of a space vehicle with a rotor which creates lift, not only does the amount of heating decrease as a result of the change of attitude of the vehicle, but also the concentration of thermal stresses as a result of the unsymmetric flow around the blades. The assumption is expressed that the maximum temperature of the blades of a rotor intended for returning a space vehicle will be 900°C. For a reduction in thermal stresses, it is proposed to use rotors with hollow blades, inside which cooling liquids or gases circulate which are transferred along the blades under the action of centrifugal forces.

In foreign literature calculations are given for the descent and landing of one of the stages of a "Saturn-1B" carrier rocket with the aid of a rotor device. It is proposed to return this stage to the point of launch after one revolution around the earth. The "rocket – rotor" system forms a maneuverable gliding vehicle having a lift-drag ratio of 1.15 at hypersonic flight speeds. Such a lift-drag ratio ensures, as noted, a lateral gliding range of ±1980 km. The weight of the driving elements of the rotor system comprises 545 kg, or 7.9% of the gross weight of the descending vehicle.

Calculation was also made for the landing of an "Apollo" spaceship with the aid of a rotor device. It showed that the landing speed of the "Apollo" spaceship is equal to 1.83 m/s. The maximum lift-drag ratio was obtained as equal to 1.37. This value ensures a lateral range of ±2110 km.

From the aforesaid, it is evident that in the way of creation of piloted aerospace vehicles there still stand several problems. But there is no doubt of the fact that they will be solved by the total efforts of the scientists, designers, and engineers.