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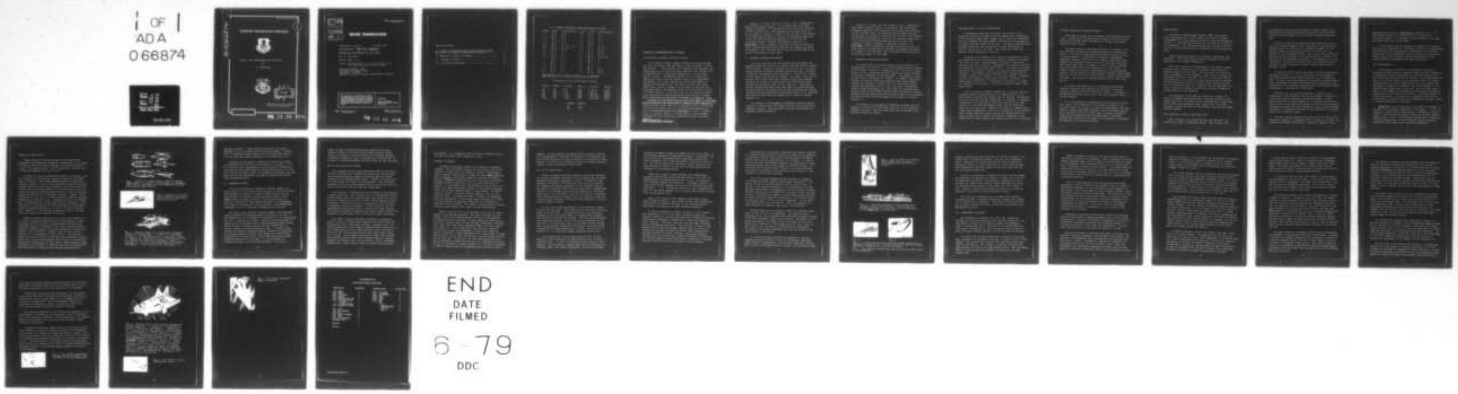

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BETWEEN THE STRATOSPHERE AND THE COSMOS

By

G. Nesterenko

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By: G. Nesterenko

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

BETWEEN THE STRATOSPHERE AND THE COSMOS

G. Nesterenko, Candidate Technical Sciences

To fly faster, higher, farther tomorrow than today has been the motto of aviation from the moment of its conception. Solving this problem the scientists, the designers, the engineers, the technicians, and the factory workers, who build the aircraft, and the associations of flight-test organizations have attained enormous results. Contemporary aircraft fly ten times faster, higher, and farther than the machines built at the beginning of our century. The series fighters are now already capable of flying at speeds greater than 3000 km/h, one and a half times faster than a bullet, climbing to an altitude of 30-35 km, and long-range bombers and passenger liners will fly 10,000 to 15,000 km without landing. In the second half of our century artificial earth satellites and manned spaceships opened the era of speeds above 28,000 km/h and altitudes of hundreds of kilometers. Thus,

Thus, man now confidently flies in the lower layers of the stratosphere, accumulates the experiences of flights in outer space, and is acquainted with speeds from zero to 3000 and 28,000 to 40,000 km/h. But yet speeds between 3000 and 28,000 km/h and altitudes from 35 to 150 kilometers prove to be unmastered, a "void." There is as yet no aircraft capable of steady flight in this seemingly "intermediate zone" separating contemporary aviation and astronautics.

From foreign press materials

Nature, it is said, does not tolerate a void. Technology in many respects repeats nature. It is natural that scientists, designers, engineers, and technicians have turned their attention to this "omitted" zone. The knowledge and the means which man has now makes it possible to arrive at the solution of the problem of building "space aviation," vehicles for mastering speeds from 3,000 to 28,000 km/h and altitudes from 35 to 150 km. Our scientific reviewer, Candidate of Technical Sciences G. N. Nesterenko, tells us about the direction in which the search is being conducted and what kind of aircraft and engines are needed for flights in the "unfilled" zone of speeds and altitudes in his article which begins in this issue.

I. HYPERSONIC AIRCRAFT AND ENGINES

In recent years more and more research and development are appearing which are devoted to so-called aerospace vehicles capable, in the authors' concept, of carrying over into the field of astronautics the more economical aviation designs and flight principles to replace or supplement rocket principles. Accordingly, a number of very logical reasons are put forward. Jet engines [VRD] used in aviation are several times more economical than rocket engines. Aircraft are vehicles of repeated use, but contemporary launch vehicles and spaceships are, as a rule, used once. Furthermore, several foreign specialists claim that under the conditions when reliable means of anti-missile and anti-space defenses are created, aerospace aircraft maneuvering in the upper layers of the atmosphere may become the most effective weapon for the attack of various targets, etc.

The research and development of hypersonic aircraft and jet engines for them are the first step on the way to the creation of aerospace aircraft. They have given many new, interesting, and sometimes unexpected results.

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The Mach Number is a Unit of High Speeds

Contemporary science has developed a set system for the gradation of speeds of flight in the air medium, and, accordingly, of the aircraft, power plants (engine units), and other components, which are designed for these speeds. The speed of the propagation of sound in air was adopted as the unit. According to predetermined standard conditions, near the ground it equals approximately 340 m/s, that is about 1200 km/h. True, this unit varies and depends on the temperature of the air.

On ascent to an altitude up to 11 km, the temperature of the air (according to the international standard atmosphere) decreases from +15°C to -56°C. Correspondingly, the speed of sound also decreases from 340 to 296 m/s. Consequently the speeds of aircraft are defined by the so-called "Mach" number. This number represents the ratio of the speed of flight to the speed of sound under given conditions. Accordingly, the following "speed" designations of aircraft, engines, air streams, etc. have been adopted: "Subsonic" (a speed not exceeding 0.9 the speed of sound), "Transonic" (a speed equal to Mach 0.9-1.2), "Supersonic" (from Mach 1.2 to Mach 5), "Hypersonic" (from Mach 5 to orbital velocity), "Space" (Over 28,000 km/h).

Such a division is somewhat formal, but it reflects well the profound physical differences which are characteristic of the interaction of aircraft and engines with the airflow. We emphasize the word interaction because conceptions of "subsonic," "transonic," "supersonic," and "hypersonic" may relate only to the air (gas) stream and to aircraft and engines used in the air medium and which use it in some form. Therefore we cannot for example call a rocket engine "hypersonic," even if it is installed on an aircraft which attains hypersonic speed, because the working process of such an engine and its thrust are virtually independent of the medium and the flight speed of the vehicle on which it is installed.

The Main Problems of Hypersonic Flight

Each range of speeds has its inherent characteristic peculiarities. Consequently, the problems which must be resolved in the building of aircraft which are capable of flying at hypersonic speeds are also specific.

The first problem is the power plant for the aircraft. Not one existing jet engine yet provides acceleration to hypersonic speed. It is able to attain hypersonic speed only with the help of rocket engines. In particular, on America's experimental hypersonic aircraft, the "X-15," for example, liquid-fuel rocket engines with a maximum thrust of nearly 25 tons were installed. The rocket engine made it possible to attain a speed of approximately 7,000 km/h for a short distance on one test flight. On another flight an altitude of approximately 107 km was achieved. However, the fuel supply for self-sustained "powered" flight lasts only 80 s. Then the "X-15" can only glide, quickly losing altitude and speed. As a result its maximum range is only a little over 600 km.

Of course, such data may not be considered satisfactory. Therefore scientists and engineers are striving to build more efficient engines suitable for hypersonic speeds. According to contemporary opinions, these can be only ramjet engines (PVRD) of special designs.

The second problem is overheating of the structure at hypersonic speed. The temperature of the exterior surfaces of an aircraft flying, let us say, at a speed of approximately 9000 km/h (Mach 8) reaches almost 9000 degrees. Without intensive cooling of the structure any kind of long flight is simply unthinkable. These two main problems produce a great number of secondary problems and complications on whose solution depends the building of hypersonic and aerospace aircraft.

Ramjet Engines

The idea of building ramjet engines (PVRD) was proposed about sixty years ago. At the present time there are various configurations for such engines (several of these are represented in Fig. 1). The principle difference in the PVRD is the absence of a compressor. Air compression before fuel injection and combustion is accomplished only by ram pressure of the incoming airflow.

Ramjet engines are divided into subsonic, supersonic, and hypersonic. The flight speed for which the engine is rated is determined by its design configuration.

The entire history of the development of the PVRD is characterized by the constant struggle and unique competition with aviation engines of other types. Until recently, the PVRD more often lost than won in this struggle. This is due to several disadvantages inherent in the PVRD. First of all with the lack of self-sufficiency it is unable to start and accelerate an aircraft. The starting and operation of the PVRD itself requires an inlet flow of considerable velocity. Therefore they are employed, as a rule, as sustainer engines, in particular supersonic engines on several types of cruise missiles.

The advantages of the PVRD are simplicity of design, the absence of highly-loaded moving parts, and high efficiency under design conditions. At present it is considered that at high supersonic speeds, corresponding to Mach numbers over 4, and with hypersonic flights the PVRD are more suitable than the most modern turbojet engines.

The Combustion of Fuel in Hypersonic Flow ...

Until recently it was considered that even PVRD were not suitable for flight at supersonic speeds. Then we came to the conclusion that they are able to provide a speed of Mach 5 to 7. The obstacle to further increasing the speeds at which the PVRD is able to produce thrust is the so-called available temperature drop.

The fact is that in the PVRD which have existed up to now, just as in turbojet engines (TRD), the airflow is decelerated and compressed prior to entry into the combustion chamber. At low subsonic speeds of the airflow (from 80 to 160 m/s) fuel is injected in the combustion chamber. But if up to such a speed the airflow entering the engine of an aircraft flying at Mach 7 to 8 decelerates, its temperature increases to 2000 degrees due to this compression. Injection of kerosene under such conditions gives virtually no more temperature increase and the engine ceases to increase thrust.

To obtain effective thrust with flight (airflow) speeds which correspond to Mach 10 to 15, in recent years it was proposed to use liquid hydrogen rather than kerosene as fuel for hypersonic PVRD. By this (using liquid hydrogen) the engine operating temperature is somewhat increased, since appreciable dissociation (decomposition) of the combustion products with heat absorption begins in hydrogen at temperatures of 3500-4000°C.

The main, you could say revolutionary, discovery in the development of the hypersonic PVRD was the proposal for going to a specially designed supersonic combustion chamber. It was demonstrated that in ramjet engines it is advisable to decelerate the air only to such speed and pressure at which there is achieved spontaneous ignition and stable combustion of the injected hydrogen and there is a significant increase in the temperature of the airflow in the combustion chamber.

The most suitable temperature of the air at the inlet of the combustion chamber of a hypersonic PVRD is thought to be 820°C. In conventional engines (with subsonic combustion chambers) such a temperature is reached at flight speeds of Mach 4.5 to 5. At Mach numbers above 6, to obtain 820°C at the inlet of the combustion chamber it is necessary to have supersonic flow along the entire inner duct of the engine.

At the present time the fundamental possibility of building PVRD with fuel combustion in a supersonic flow has been demonstrated theoretically and experimentally. Nevertheless, the practical realization of this possibility and the application of hypersonic ramjet engines with supersonic combustion chambers meet with numerous design, technological and other difficulties.

The "Flying Engine" ...

Calculations, projections, and analysis of the possible structural configurations of hypersonic PVRD and their arrangement on hypersonic aircraft demonstrated by foreign scientists that one more serious obstacle lies in the path: the excessively large size of the frontal surface of the hypersonic PVRD. The higher the Mach number for which a hypersonic aircraft of a given size and shape is designed, the larger in size the PVRD must be. The engine becomes larger than the aircraft. Thus, at Mach numbers above 10 for example, the necessary area for engine air intake is already equal to the mid-section (that is, the cross section) of the entire aircraft. The thrust of a hypersonic PVRD at these flight speeds is adequate only for overcoming its own drag. There is simply nothing left for aircraft.

One way out of such a situation is "to hide" the aircraft, to include it in the overall dimensions of its engine. ... Thus the hypersonic aircraft with a PVRD becomes in principle a "flying engine." In this case the kinds of shapes the aircraft take are shown in Figs. 2 and 3. The presented designs were developed in the United States under the name "Scramjet" which in expanded translation means "ramjet with supersonic combustion."

Flight on a "Fire Broom"

Design studies of various versions of hypersonic PVRD demonstrate that supersonic combustion chambers prove to be larger in diameter than the aircraft fuselage, and relatively short in length. The question arises: does the hypersonic aircraft need a combustion chamber outer cover at all?

It turns out that at certain Mach numbers it is possible, and even advisable, to discard the combustion chamber in the normal sense of the word. Thus, there appeared designs of hypersonic aircraft (engines), to put it more accurately, combined "aircraft-engine" systems with "external combustion," that is, with burning of fuel, not in a special chamber, but in shock waves and in the external supersonic flow which flows around a conical or specially shaped tail section of the hypersonic aircraft. (Figure 1 shows schematics (a), (b), and (c) of such hypersonic PVRD with external combustion in supersonic flow). "Scramjet" aircraft, for example Fig. 3, essentially are aircraft with external combustion. They must fly as if resting on a fire plume produced by the burning of streams of hydrogen expelled in the flow. The old fairy tale about flights on a "fire broom" automatically comes to the mind of one who sees such an aircraft in the air.

Numerous materials published in the press about research in the field of hypersonic PVRD show that the development of space technology and the striving to develop aerospace aircraft and spaceships capable of returning to their base "like an aircraft" stimulate continued work in the field of hypersonic aircraft and engines. From a scientific viewpoint there are now no basic obstacles to the development of such aircraft. The problem of thrust is solved by the use of PVRD with fuel combustion in supersonic flow. Using liquid hydrogen, which offers not only greater heat-producing capability but also greater thermal capacity, makes it possible, in principle, to solve not only the fuel problem but also the problem of cooling of the exterior surfaces of the

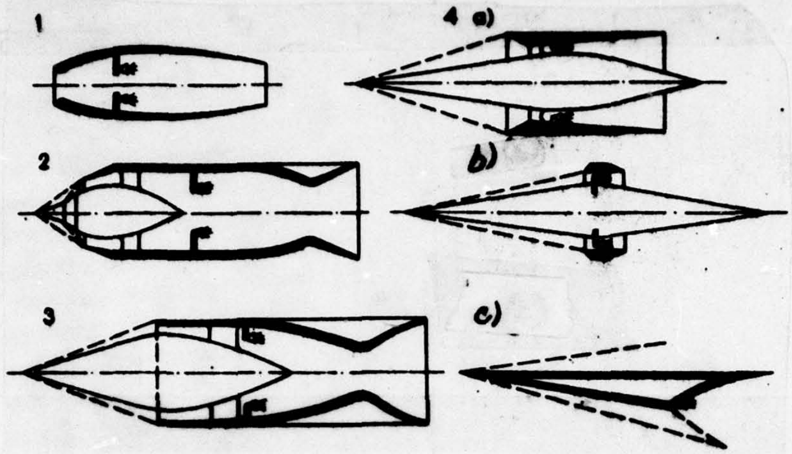

Fig. 1. Sketches of ramjet engines (PVRD) for various flight speeds: 1) subsonic, 2) supersonic, 3) hypersonic (Mach 5-7), 4) hypersonic with fuel combustion in supersonic airflow (above Mach 7).

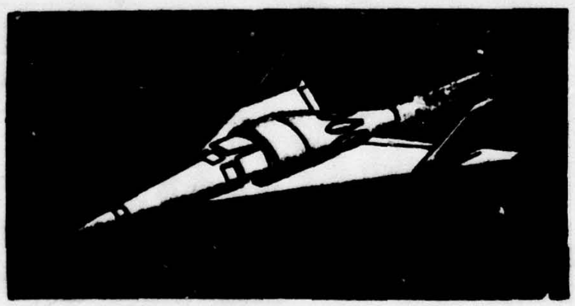

Fig. 2.A design for an experimental hypersonic vehicle for testing PVRD at speeds from Mach 3 to Mach 12.

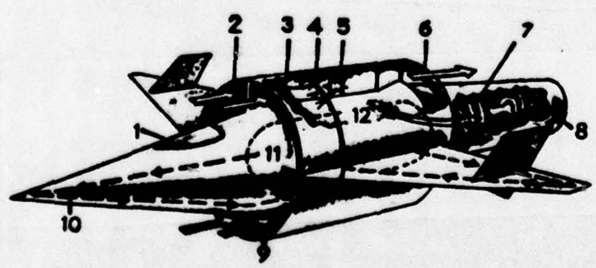

Fig. 3. Component design of an experimental "Scramjet" vehicle for testing PVRD. 1 - cockpit; 2 - supersonic airflow; 3 - aircompression area; 4 - injection of fuel; 5 - ignition; 6 - accelerated flow of combustion products; 7 - turbojet air intake for low speeds; 8 - TRD; 9 - air intake of the four-section hypersonic PVRD around the fuselage; 10 - fuel line for cooling the nose cone and wing edges; 11 - fuel collector; 12 - fuel tank.

hypersonic aircraft. Before entering the engine, the liquid hydrogen is fed to the most heated structural elements. Cooling them, the hydrogen becomes vaporized and preheated which permits its most rapid and complete combustion in the supersonic flow.

Research and development of hypersonic aircraft and engines are considered the next step in the evolution of aviation. It is as if aviation were "approaching" a little closer to astronautics. This research has revealed many new difficult problems, but at the same time has provided a number of findings and successful solutions which open up the possibility of flight at speeds and altitudes not yet mastered by man.

II. AEROSPACE AIRCRAFT

After the development of hypersonic aircraft designs, the speed of which is five times or more the speed of sound, scientists and designers of a number of countries began research into the possibilities of building so-called aerospace aircraft (VKS). These aircraft are able to take off from an airfield like an aircraft, accelerate to high hypersonic speeds in the atmosphere, enter space for carrying out various missions, then re-enter the atmosphere, fly in it, and make a landing like an aircraft.

The idea of using aircraft, aviation engines, and aerodynamic flight principles for achieving space velocities is not new. It was examined even by the founder of astronautics, K. E. Tsiolkovskiy and by F. A. Tsander, and others. However, at that time when the speed of even the specially built record-breaking aircraft did not exceed 700 km/h, achieving orbital velocity (28,000 km/h) by aircraft seemed an unfounded fantasy to many. At present, when aviation has mastered supersonic speeds, and when the possibility of building hypersonic aircraft has already been scientifically demonstrated, striving to take a step forward which would permit elevating aviation to a new stage — to the achievement of transpace and space velocities and altitudes — is natural. A number of large aircraft-manufacturing firms and scientific research centers of the United States, Great Britain, Federal Republic of Germany, and other countries have already conducted preliminary research in order to determine how realistic are the prospects of building aerospace aircraft within the next few years.

Why is Such an Aircraft Needed?

The mastering of outer space, which was begun by the Soviet Union on 4 October 1957, demonstrated that launch vehicles which were being improved were capable of putting larger and larger vehicles into circumterrestrial orbits. However, the per kg cost of lifting cargo into space is extremely high. Some scientists consider that if only nonrecoverable launch vehicles are used for this in the future, then the cost will remain high.

The high cost of launching each kg of payload is explained by a number of reasons. One of them is that the contemporary launch vehicle stages, which have depleted their fuel supply burn up with all their equipment upon return to earth. Rocket engines are very "voracious." Aviation, that is, jet engines are very economical in comparison with rocket engines. In recent years it has been demonstrated theoretically that on aviation type winged aircraft with specially designed combination and ramjet engines (PVRD) it is possible to attain speeds close to orbital and space velocities.

The "ideal" aerospace aircraft, according to contemporary opinion, would be a single-stage winged aircraft which takes off horizontally from a conventional airfield. Equipped with a combination power plant, which permits achieving space velocities, it could independently go up to high altitudes, service artificial satellites and orbiting space stations and convey cargo, people, etc., to them. After completing its space flight, this aircraft must decrease speed and enter the atmosphere gradually, without excessive overheating, and, like an aircraft, reach a designated landing point. Such a vehicle could be operated long-term like an aircraft. It is suggested that this would noticeably reduce the cost of putting a kg of payload in orbit

Problems of Engines

Building an aerospace aircraft is an extremely complicated business. One of the main problems far from being solved is the problem of a power plant for aerospace aircraft. In the whole range of speeds and altitudes of flight for which such an aircraft must be designed, only rocket engines can operate successfully. However, rockets are inefficient and the very idea of building an aerospace aircraft assumes the use of the more efficient jet engines. At the present time, unfortunately, there is still not a single such engine sufficiently capable of efficiently producing thrust in the whole required range of flight speeds. For speeds from zero to Mach 3 the most efficient engines so far are the turbojets (TRD). At speeds from Mach 3 to Mach 6 the supersonic PVRD are advantageous. In the speed ranges from Mach 5-6 to Mach 10-15 and greater the hypersonic PVRD with fuel combustion in supersonic flow are needed. For flights at speeds close to orbital velocity rocket engines still remain the most advantageous.

Thus, it turns out that it is necessary to put all the listed engines on an aerospace aircraft. But this, of course, is inexpedient, since their combined weight "eats up" all the payload. A different way out is proposed: create combination power plants for such an aircraft which, as the aircraft accelerated, would work first like a TRD, then like a supersonic PVRD, then like a hypersonic PVRD, etc. Such a quest led to the idea of a so-called "convertible" engine, the parameters of which would change in order to constantly be most advantageous for a given stage of flight and its speed. As yet there has not been found the actual realization of this idea. Actually, we are only talking about the fact that an aerospace aircraft with the help of a combination VRD would be able to accelerate to speeds of Mach 10-15. Further acceleration to orbital velocity would be accomplished with the help of rocket engines. In many designs of aerospace aircraft turbojet engines are incorporated for launching, for flying in the atmosphere, and upon return from space, but all acceleration is provided by rocket engines. But with such a propulsion system an aerospace aircraft becomes a heavy, uneconomical rocket plane.

But If Not Single-stage ...

Several foreign specialists carrying on scientific research and design development work came to the conclusion that an "ideal" aerospace aircraft was impossible to build. Furthermore, they generally cast doubt on the practical value of such an aircraft. For example, West German specialists of the "Boelkow" firm, as the result of research, came to the conclusion that a single-stage version of the aerospace aircraft would inevitably be extremely heavy and not very efficient. Into orbit will go not an aircraft with a favorable power-to-weight ratio, but actually an empty but extremely heavy container for the fuel which was spent in accelerating to orbital velocity.

In fact, the energy expenditures for acceleration to space velocity are very great. Fuel comprises more than half the launch weight of the aircraft. Calculations done by many researchers demonstrate that the launch weight of a single-stage aerospace aircraft must be 200-220 tons minimum. The fuel, liquid hydrogen, will weigh approximately 100-110 tons and the remaining 100-110 tons will be the large fuel tanks, the airframe, and the engines. There is practically nothing left for payload. According to the calculations of foreign specialists, in order to put in orbit a payload of 2 to 3 tons would require launching 250-300 tons.

Let us assume that such a single-stage aircraft is built. Taking off like an aircraft and expending almost all its fuel, it goes into orbit. In order to rendezvous with an object it must maneuver. But the massive, large-tonnage vehicle consisting of a fuselage, wings, fuel tanks, landing gear, and other structures completely unneeded in space, no longer has fuel in the tanks. It was expended, primarily, in getting into space. Furthermore, the possibilities for maneuvering such an aerospace aircraft are either completely nil or they are minimal. But this is still not all. The crew is faced with a question: how to decelerate the heavy aircraft in order to put it into the dense layers of the atmosphere at an allowable speed.

These and a number of other problems with single-stage aerospace aircraft have forced many specialists to conclude the inadvisability of building such aircraft at all. The majority favor building compound, two-stage and three-stage, aircraft. In recent years several designs for such aircraft have been developed (see Figs. 1, 2, 3). The special feature of these aerospace aircraft is that rocket engines, not jet engines, are used for acceleration and gaining altitude.

Why, in the concept of the designers, must they be multistage aerospace aircraft? Why, in spite of the most overwhelming difficulties, is research conducted in this field with great persistence, especially in the West European countries?

It can be explained by a number of reasons. One of these is that depending on the level of their economic potential the European countries do not have the capability of rapidly developing space-rocket technology, in particular, of producing large-size launch vehicles. Therefore, they look for other more economical ways of penetrating outer space. The scientific circles of Great Britain, France, and West Germany consider that the building of repeated-use aerospace systems (so-called "space transporters") are more justified for their countries. Multistage aerospace aircraft must in concept become a means of transport for carrying out routine flights on "Earth-orbit-Earth" routes and at the same time take their own place in outer space research programs.

How realistic is this goal? Estimates and research conducted in a number of West European countries, according to the assertion of scientific circles, indicate that building special aerospace aircraft will require approximately 10 to 15 years. In order to reduce this time, some propose examining the possibility of using existing aircraft for the first stage of aerospace systems. Although not one of these proposed designs is considered suitable for practical realization, the specialists do not give up. They continue to look for new solutions.

One of the unique designs proposed recently is a design of the aerospace aircraft "Mastard" which means "multiplied." The vehicle is built by putting together several aircraft (Fig. 1). The use of the "modular principle" is the characteristic of this aerospace system which distinguishes it from multi-stage aerospace aircraft proposed by the "Junkers" and "Lockheed" firms (see Figs. 2 and 3). The system is composed of three rocket-planes (modules) of almost identical weight and construction. One of them carries the payload, goes into orbit, and is a spaceship. The two other rocket-planes serve only as boosters. After accelerating the first ship with the payload, they return to the airfield.

Having carried out its mission in space, the orbiting module (Fig. 4) also re-enters the atmosphere. The shape and heat-shielding of its hull, by design, must withstand aerodynamic heating of friction and permit flight to its airfield. The weight of each module according to the design is about 140 tons, and the whole system with a payload of 3 tons weighs about 430 tons. Thus, in this version, too, the results obtained is still unfavorable: the weight of the payload comprises less than one percent of the launch weight of the system.

In the United States a proposal was advanced to develop a compound aerospace aircraft by using an experimental supersonic bomber "XB-70A" (maximum Mach 3) as the first stage and a rocket-plane "X-15A" (its maximum speed up to Mach 8) as the second stage.

Fig. 1. How the "Mastard" aerospace system might appear at launch. Rocket engines are ignited on all modules.

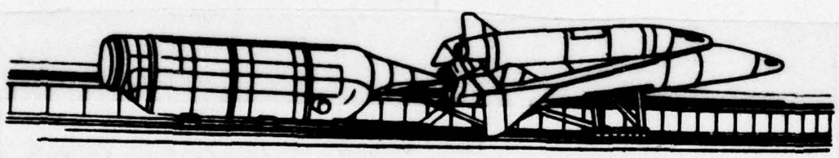

Fig. 2. A two-stage aerospace aircraft design by the "Junkers" company (West Germany). Initial boost is provided by a rocket trolley which could be considered as the third stage of the aircraft.

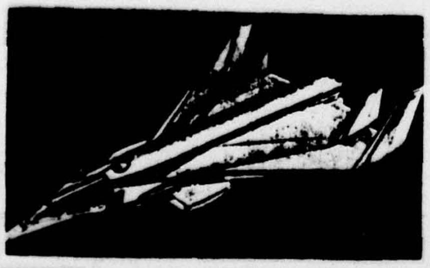

Fig. 3.

Fig. 4.

Fig. 3. A three-stage aerospace aircraft design proposed by the "Lockheed" company (U.S.A.). Rocket engines are used for acceleration and jet engines for return of the stages.

Fig. 4. The "Mastard" system space module enters the dense layers of the atmosphere.

However, calculations showed that with the external hanging of the rocket-plane, the "XB-70A" aircraft could not fly at supersonic speed. Therefore, the overall speed which could be achieved by the system ("XB-70" + "X-15") even with the "X-15" being equipped with a hypersonic PVRD, will amount to only about 9000 km/h, and not the required 28,000 km/h.

In spite of significant successes of aviation in the struggle for increasing the speeds and altitudes of flight, they are still far from space velocities. The question of expediency of use of aircraft, jet engines, and aviation flight principles for stages of acceleration and putting the spacecraft into orbit remains open. However, research and experiments directed at solving the problems of building an aerospace airoraft continue.

With much more confidence they now conduct work abroad in building new types of spaceships having hull shapes which produce lift in flight in the atmosphere. They will be placed into orbit by the launch vehicles and return to base like an aircraft after descending from orbit.

III. RECOVERABLE SPACECRAFT

The contemporary spaceship, as a rule, has a shape more favorable for so-called ballistic entry into the atmosphere. For this there is included on the ship an onboard retropackage in order to descend from orbit. The speed of the ship becomes less than orbital velocity and it, like an ordinary missile, begins to pierce the upper rarefied layers of the air envelope of the Earth.

As a result of air drag, deceleration occurs and at the same time, heating of the surface of the ship. It heats to 1500 to 2000 degrees. The antennae, the brackets, and other protruding parts break off and burn up. But, thanks to a special coating and the high strength of its hull, the ship remains intact. Upon decreasing speed to a certain rate the parachute is ejected and the ship touches down.

However, ballistic re-entry to the Earth already ceases to satisfy the scientists and designers. They are working on building manned spaceships which would be capable of maneuvering and flying in the atmosphere after descending from orbit, of locating their base, and making a landing like an aircraft. Such ships, which are controllable not only in space but also when flying in the atmosphere just as aerospace aircraft, fall into the class of aerospace vehicles since they combine the characteristics of spaceships and conventional aircraft.

One of the main features of the aircraft-like recoverable spaceships is that in flight in the atmosphere they are capable of generating aerodynamic lift and aerodynamic control moments for maneuvering. Thus, these vehicles, like aerospace aircraft, (VKS), incorporate space and aviation technology. The distinction is that the aerospace aircraft is an aviation vehicle developed to space capabilities, but the aircraft-like recoverable spaceship is its "counterpart" on which the advances of aviation technology and aerodynamics are employed. In the first case the development proceeds from aviation to astronautics, in the second — from astronautics to aviation.

Experience accumulated by world-wide science and technology during the development of manned spaceships and the first rocket-planes helped to approach the practical designing and building of experimental spaceships having special aerodynamic shapes for aircraft-like return to their base, and repeated use. Such aircraft were developed, in particular by several U.S. firms.

Besides the feature of aircraft-like return to its base, the aerospace vehicles, according to the designers' calculations, are subjected to considerably lower g-forces upon entering space and upon return to Earth. Consequently, temperature conditions of aerodynamic heating are also less intense on them. These two advantages over contemporary spaceships which re-enter the atmosphere on a ballistic trajectory, open up broad prospects for such type of vehicles. It is no accident that development of aerospace vehicles is conduced in a number of countries at an increased tempo. In the United States, for example, there is a special program under the code name "Start," divided into two major subprograms "Prime" and "Pilot."

The "Prime" program involves carrying out research and development of precise recovery from space including maneuvering entry into the atmosphere and subsequent aerodynamic flight. The "Pilot" program includes fundamental testing of experimental and training aerospace vehicles at low speeds, working out piloting procedures during flights in the lower layers of the atmosphere, and selection of landing methods. (By low speeds and altitudes in this case we mean altitudes below 30 km and speeds up to 2000 km/h.)

The procedures for these flight tests were about the same as the procedures for the experimental flights of the "X-15" rocketplanes (X-15 results were carefully considered and used in the "Start" program). The test vehicle is suspended under the wing of the "B-52" mother-ship. At an altitude of 12-14 km the vehicle is released from the mother-ship and, manned by a pilot, it accomplishes a gliding flight and landing, or the pilot, having ignited the liquid-fueled rocket engine installed on the vehicle, accelerates and gains altitude and then glides to a landing. On such test flights various types of maneuvers are practiced, stability and controllability, also landing characteristics of these unusual and still strange vehicles are checked.

In 1966 an aerospace vehicle, the "M2-F2," (see Fig. 1) was built in the United States. Its weight was only 2.5 tons. The first test took place in July. After separation of the vehicle from the ("B-52") mother-ship at an altitude of 13,700 m at a speed of approximately 500 km/h, the "M2-F2," manned by a test pilot, accomplished a four-minute unpowered gliding flight during which it made two 90-degree turns and made a landing like an aircraft. Touchdown took place at a speed of approximately 300 km/h.

During 1966 and 1967 14 more test flights of this aerospace vehicle were carried out. Based on accumulated data, designers began preparing for the next stage — flight tests with a rocket engine. The engine, according to the foreign press, must by design enable the "M2-F2" vehicle to gain an altitude of 24,400 m and to develop a speed of approximately 2200 km/h.

At the end of 1966 the first test flight of another vehicle was accomplished — the "HL-10" (Fig. 2), built under the "Start" program ("Pilot" subprogram). The flight went successfully. However failures and accidients then began. Due to this, tests of both vehicles with working rocket engines which had been planned for the end of 1967, did not take place.

The designers working on the "Prime" subprogram had to endure a number of failures. Launched for the first time, the "Martin" company's unmanned version of the "SV-5D" type aerospace vehicle, fell into the ocean after re-entering the atmosphere, and they were not successful in recovering it. The second vehicle of this type, launched into space by an "Atlas" booster, was also lost. They succeeded in recovering only the third which had returned from space after injection by an "Atlas" rocket. Under the "Prime" program it was planned to launch four "SV-5D" unmanned vehicles, and only then to begin the flight tests with the manned "SV-5P" vehicles (they are now called "X-24A's", Fig. 3). But the failures with the three unmanned vehicles delayed the tests of the manned vehicles.

The great prospects of aerospace vehicles forces researchers and designers to persistently search for new solutions. In spite of failures the "Martin" company is still working on a version of a manned aerospace vehicle, not with a rocket engine, but with a jet engine. According to press reports, this vehicle, named the "SV-5J", is intended to be used for the support and monitoring of experiments with the "SV-5P" type vehicles, and also for training the pilots for them.

The design of aerospace vehicles equipped with jet engines for take off and initial acceleration indicates, in the opinion of foreign scientists, the birth of still another direction of studies which has a bearing on preliminary research of future aerospace aircraft. It is believed that if they are built in single-stage versions at all, they will have to have shapes similar to the aerospace vehicles now being developed. Specialists base this viewpoint on the fact that an aircraft must not only accelerate and enter orbit, but also return from orbit, that is, enter the atmosphere at space velocity, like the recoverable spaceships now being developed.

The characteristic feature of all the experimental aerospace vehicles being designed and already built is their unconventional shape. The original form for their hull was semiconical with a blunt nose and rounded edges. For clarifying how to better orient this semiconical shape, with the flat surface above or below, experimental vehicles are being built in both versions. For example, the "M2-F2" has a flat side which is turned up; the "SV-5P" vehicles — down; and the "HL-10" represents something midway between these two extreme versions.

The foreign press suggests that these shapes indicate the general principles of aerospace vehicle designs which are developing. It is a rejection of the usual classical configuration of contemporary aircraft, first of all of the aircraft wing which is acknowledged as unacceptable for vehicles which re-enter from space. The new principle appeared in the distinct stage still under development in the "X-20" "Dyna-Soar" rocket-plane (Fig. 4), and then it acquired its development in the "M2-F2," "HL-10" vehicles, etc.

The rejection of the wing and the transition to lifting body vehicles is, in the opinion of foreign specialists, due to the necessity of entering the atmosphere at space velocities. In order to decrease aerodynamic and thermal stress and thereby improve the safety of re-entry from space, the aerospace vehicle must be not only compact with few externally protruding parts, but also with a high ratio of internal volume to external surface area, and also with good characteristics of local and general hull strength.

Besides high strength and heat resistance, the recoverable space vehicle must also incorporate good aerodynamic qualities of stability and control during flight in the atmosphere and sufficiently low landing speed. These requirements compelled the scientists and designers to select a semiconical shape with a blunt nose and smooth contours for aerospace vehicles.

The unique configuration of the vehicles due primarily to the requirements of re-entry into the atmosphere, does not contradict but, on the contrary contributes to the satisfaction of the requirements for the optimum entry into orbit with the help of launch vehicles or other means.

Persistent research and design studies of recoverable spaceships suitable to carry out controlled flights in the atmosphere, in the opinion of a number of foreign specialists, testify to the fact that precisely in this way a practical solution to the problem of developing aviation-space technology will be found the quickest of all. The application of recoverable aircraft-like spaceships will contribute to progress in the field of building hypersonic and aerospace aircraft, to the further drawing together of aviation and astronautics.

Fig. 1. The "M2-F2" experimental aerospace vehicle suspended under the wing of a "B-52" mother-ship.

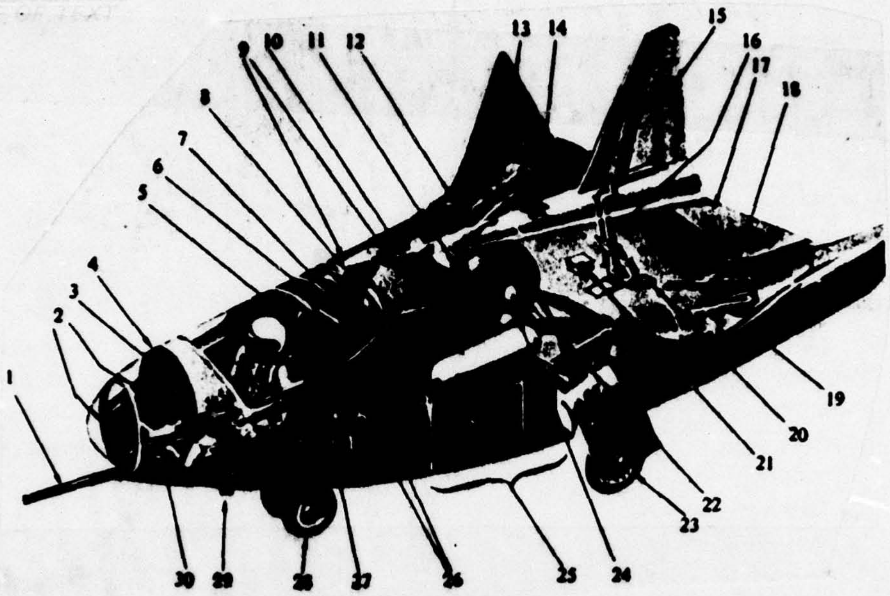

Fig. 2. Component sketch of the "HL-10" experimental aerospace aircraft. 1 - receiver for measurement of airflow parameters; 2 - windshield; 3 - right pilot's panel; 4 - anti-noise-over flange; 5 - ejection seat; 6, 7 - gyroscopes; 8 - forward fitting for attachment to "B-52" mother-ship; 9 - air tanks; 10, 11 - ballast tanks; 12 - charging connection for onboard systems; 13 - bearing and adjustable fitting for attachment to "B-52" mother-ship (2 on each side); 14 - fitting for attachment to mother-ship; 15 - rudder; 16 - rudder drive; 17 - elevon; 18 - elevon drives; 19 - ballast jettisoning duct; 20 - tail strut; 21 - electrical connector; 22, 24 - ballast air tanks; 23 - landing gear; 25 - equipment containers (left), storage batteries and hydraulic system units (right); 26 - static converters; 27 - wind turbine; 28 - nose wheel; 29 - UHF antenna; 30 - control bar.

Fig. 3. The "SV-5P" ("X-24A") experimental vehicle.

Fig. 4. The "X-20" "Dyna-Soar" space rocket-plane.

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