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16. Abstract

This booklet discusses the prospects for mastery of space and the basic problems which must be solved for future space transportation, the problems and technical difficulties which engineers and scientists will encounter during operation of the existing and determination of the future prospective transport space systems, new physical principles on whose basis one can expect a creation of more effective means of transportation in space.

The booklet is intended for a broad circle of readers interested in present-day problems of cosmonautics.

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Introduction

The successes achieved in modern cosmonautics in solving applied /3* problems graphically demonstrates the importance of a space approach in the development of Earth's civilization. Right now it is difficult to understand how we could avoid using space means in the fields of economic and scientific activity of humans such as radio and television, the weather service and seafaring, geology and geodesy, hydrology and oceanography, agriculture and protection of the environment. Space serves man and is of considerable practical use.

One can expect that in the future, using space equipment, even more important problems for human civilization will be solved -- those relating to energy and ecological limitations and their development. There is talk about putting satellite solar power plants (SSE [Satellite solar power plants, SSPP]) into near-Earth orbit and also there is consideration of industrial use of space. The former permits, taking into consideration the use of solar energy, considerably reducing the consumption of fuel-energy resources on our planet and the latter transferring part of industrial production outside of the limits of Earth where questions of elimination of waste material from production and ejection of heat could be solved without any kind of ecological limitations.

In the future we can plan and obtain outside of Earth raw material for space industry, for example, by creating ore-mining and ore-dressing industries on the Moon. In the realization of this broad-scale program of sequential and forced mastery of space whose main stages were first formulated by K.E. Tsiolkovskiy, transport space systems (TKS [Transport space system, TSS]) play an important role for the future. /4

What are the basic concepts for their development?

While in the initial stage the transport means created (rocket boosters and spacecraft) basically provided a solution for separate applied problems and demonstrated new possibilities in rocket-space engineering, right now we face more global and in practice more important goals directed at effective and economical use of space for the needs of mankind. The turning point of cosmonautics "face-to-face" with Earth caused by the essential problems of development of mankind and successes achieved in space research is characterized by the increasing volume of transport and the need to expand operations carried out in space.

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*Numbers in the margin indicate pagination in the foreign text.

The requirements for a space transportation system are changing. The universality in the use of TSS, the high productivity in the rate of launches and the value of the cargo flow realized and the relatively low specific cost of the transportation all have become more and more important. Due to the large-scale use of transport means in an era of industrialization in space, particular attention must be devoted to the problem of ecology. The realization of intensive cargo flow between the surface of Earth and near-Earth orbits in the future, and also guaranteeing delivery of lunar raw material to a main center for space industry must not lead to contamination of the environment or a breakdown in ecological equilibrium. In the first place, this circumstance must be taking into consideration when considering TSS for providing further mastery of space.

At the present time, the question of possible approaches in the development of TSS remain open: many designs for TSS of the future have been published and there are no already organized points of view for their development. A large part of the designs within the framework of short-term prediction involves improvement of transportation systems based on liquid-propellant rocket engines (ZhRD [Liquid-propellant rocket engine, LPRE]). In the foreign press, for example, designs are encountered which are completely reusable single-stage systems; however, the realization of such designs runs into a whole series of difficulties as a result of limitations in energy capabilities of the TSS based on the LPRE. TSS designs based on nuclear rocket and electric rocket engines which are more effective in their energy are being considered for use in outer space.

For all of the transportation means in space which are listed, /5
there is one characteristic common principle for creating thrust -- taking into consideration the discharge of the working substance. Then it is assumed that the mass of the working substance and the energy necessary for accelerating it is stored or produced on board the carrier. Along with this principle, in the plan for long-term prediction, other more promising principles of design are studied and used for the TSS of the future: the use of external, that is, those not stored on board, resources of energy; obtaining a thrust force by the force of a magnetic or electrostatic interaction of the aircraft with the external field; the use of thermonuclear sources of energy using external media as the working body, etc. These studies were made possible by the existing achievements and the further progress in new fields of science and technology: space, nuclear and thermonuclear energetics, laser technology, electrical engineering, the physics of plasma, quantum electronics.

This pamphlet has as its purpose, based on material published in the open domestic and foreign press, acquainting readers with interesting problems of cosmonautics with possible means of developing space transportation both manned and cargo and hybrid types. Certain designs of future transportation systems of a new type are presented in it; their use will be possible in an era of industrial conquest of near-Earth space or during organization in the future of long-distance flight in the Solar System and interplanetary expeditions.

Prospects for the Conquest of Space and Problems of Transportation

The launch of artificial Earth satellites. The very first operation of the TSS was the launch of the artificial Earth satellite (AES). The first satellite did not solve applied problems but itself in the operation of putting the AES into flight in orbit around Earth was a great achievement of science and technology for that time. When the first communication satellite was launched on April 23, /6 1965 in the Soviet Union, the Molniya-1, the inhabitants of Vladivostok for the first time could look at the parade and demonstration in Red Square simulatenously with people in Moscow. In a very short time in our country, an operational satellite communication system was developed and put into operation ("Orbita") which made it possible for tens of millions of inhabitants of the Far East, Siberia, the Far North and Central Asia to utilize the wealth of space communication and retranslation.

On June 25, 1966, the first Soviet meteorological AES was launched and after a year the Meteor space meteorological station was created which includes reception posts, processing and propagation of information. The use of meteorological satellites basically increases the efficiency of weather prediction for the national economy. The AES were broadly used also for nagivation of ships in the fishing, transport and scientific fleets. Today, in our country, satellite systems for telephone and telegraph communication are being effectively operated as well as transmission of television and radio broadcasting programs, and the proofs of central newspapers. Using photography in orbit there is reconnaissance of useful minerals, plans are drawn up for irrigation and flooding, prediction of harvests, they outline variations of routes for projected roads, blinds for electric transmission, petroleum and gas lines, and in particular the design for laying one of the railway tunnels on the BAM [Baykal-Amur Trunk Line] route is specified.

Similar satellite systems have been developed in the USA and are being developed in other countries. At the present time, international satellite communication systems are in operation, the Intersputnik and the Intelsat, services which are used by more than 120 countries on all of the continents of the world. With the participation of the USSR, work is being done on creating an international global satellite system for maritime communication, the IMMARSAT and a satellite system, the COSPAS-SARSAT system for finding ships and aircraft which are in trouble.

What are the prospects for developing satellite systems in near-Earth space from the point of view of their transport supply?

The space orbital means are constantly being improved. The onboard systems are being unified, the guaranteed lifetime for oper- /7 ation of onboard equipment of the AES is increasing, the dimensions of the antennas and power of the transmitters are being increased, satellites are being equipped with microelectronic processors and complex circuits for switching of signals. At the same time, the altitude for the operating orbits of the AES is increasing. Recently, space systems using stationary AES became more and more prevalent; these were launched into circular equatorial orbit (with an inclination of about 0°) and an altitude of about 36 thousand km.

The broad zone of survey of the surface of Earth and the possibility of continuous observation and continuous transmission or reception of information from Earth by the stationary AES reduce the number of satellites in the system. Along with this, the introduction of stationary AES requires more powerful multi-stage rocket carriers and therefore it is not surprising that up until 1981 the launch of such AES (if they were not considered experimental) was done only using Soviet and American rockets. But the value of the cargo flow to a geostationary orbit is ever increasing as improvements are made. If the weight of the first communication AES introduced into geostationary orbit amounted to tens of kilograms, the weight of future stationary AES, in the opinion of specialists, can be calculated in tons.

For example, according to the estimate of certain foreign specialists, the weight of the control AES for a network of electric transmission lines and petroleum and gas pipelines (retranslation of the readings of censors to the lines) will amount to 4.5 tons, the AES for a future telecommunication system -- 6.35 tons, the AES of the system of retranslation of postal dispatches (electronic mail) is 9.1 tons. Due to the complex character of research for a single AES (based on a unified space platform) the weight of the stationary AES will grow even more.

The number of launches of stationary AES is increasing. Right now, several dozen AES have been launched into geostationary orbit including up to 30 Soviet satellites. In the period from 1980-1990 the foreign stationary AES alone will amount to about 200. Thus, during operation of future AES in the information system, the value of the expected cargo flow will be calculated by hundreds of tons per year (which is acceptable for TSS on a LPRE base) and transportation operations will be made basically on the "Earth-geostationary orbit" route using a low near-Earth orbit as the transfer base for the rocket-carriers and the inter-orbital transportation means.

From manned stations to space settlements. While the launch of the first AES mark the beginning of the study of space using automated equipment, the first space flight of a human also accomplished by the Soviet Union determined the second most important approach to the conquest of space -- using manned equipment. It received its logical development in the program of long-term orbital stations -- the "main line route for man in space." /8

The outstanding features of the orbital station (OKS [Orbital Space Station, OSS]) as a space object are the presence of a human on board, the duration of functioning in orbit and the adequately broad circle of national economic and scientific problems which can be solved. The presence of a man on board the OSS significantly increases the effectiveness of scientific research and experiments; he can conduct adjustment, repair-prevention and other operations for servicing of the station.

In principle, different variation are possible for constructing the OSS: its assembly on Earth and putting it into orbit as a unit using the principle of docking only for equipment operations; assembly of the OSS in orbit from separate elements delivered from Earth using a special assembly team of cosmonauts, etc. But in all probability, a combined method based on the so-called unit assembly system in space will have the most practical use in the near future. The space stations will be assembled directly by joining various functional modules including the living, power and research modules. For fulfilling missions, specific research modules will be replaced with new ones. The TSS will provide delivery of modules into orbit and also regular cargo-passenger trips for equipping the stations.

At the present-day stage in the Soviet Union, the Salyut OSS is operating with a crew of 2-5 persons (weight of the station with one docked spacecraft -- 25.6 t), their modification and equipment with scientific-research equipment is carried out in accordance with the new programs of research. The following data are included in the /9 field of manned flights. The flight of the Salyut-6 OSS has been continuing for about 5 years during which time 5 basic expeditions and 11 visiting expeditions have been launched, 35 dockings of manned and cargo transport craft have been accomplished as well as three trips of cosmonauts into open space. The duration of the flight of one of the crews amounted to 185 days and on the Salyut-7 OSS launched on April 19, 1982, the time that the first crew stayed there reached 211 days.

In the future, with an increase in the scale of problems solved in space, OSS will appear which will carry out the role of an intermediate station for transport communication in near-Earth space and for flights to the Moon; the OSS for conducting assembly work in space -- "space shipyards"; the OSS settlements which service industrial orbital complexes, etc. Such stations will be considered for functioning during decades with crews of several tens and hundreds of persons and will have powerful solar or atomic power plants.

Even more grandiose plans exist for organizing space settlements which were first discussed by K.E. Tsiolkovskiy. At the present-day stage, one of the projects was proposed by a professor at Princeton University, O'Neil. In this plan several models of space settlements are considered: the first model is calculated for 10 thousand persons and the second for 200 thousand persons, etc. The design of the settlement consists of two cylinders connected by cables which rotate in opposite directions along a longitudinal axis creating artificial gravity. In the cylinders which are 90 km apart from each other, transparent compartments are planned with which one can regulate the inflow of solar energy and simulate an ordinary 24-hour cycle. Inside the cylinders are living quarters and lawns.

The construction of the first model can be characterized by the following figures: number of builders -- 2 thousand persons, total weight of the structure -- 500 thousand tons. Of this weight only 10 thousand tons (necessary equipment, tools) need be delivered from Earth; the rest of the weight of the structure is prepared on the OSS from raw material delivered from the Moon. Then the first model uses an industrial base for the construction of the second model, etc. Of /10 course, such projects would hardly be realized in all their details but considering them will lead to the necessity for complex developments stimulating in this way studies in related fields of cosmonautics, in particular, in space energetics, space production and, of course, space transportation.

Solar electric power plants in orbit. One of the global problems for space transportation of the future will be a program of deploying a near-Earth system of satellite solar power plants (SSPP). The idea of creating SSPP recently has taken on more and more importance among the large-scale future space problems. The need in this direction for work is dictated, first of all, by striving to solve the energy problem of Earth while retaining an ecological equilibrium on our planet. Although the reserves of petroleum, coal and gas on Earth are still large, they are indeed finite. At this time, the worldwide demand for energy amounts to $3 \cdot 10^{20}$ J per year, that is, in all a total of about 0.01% of the energy which the Earth receives from the Sun.

Then, one is still only surprised by the genius of K.E. Tsiolkovskiy who wrote: "...almost all of the energy of the Sun which falls at this time is useless for mankind... What is strange about the idea of utilizing this energy!"

The need for energy on Earth is increasing constantly -- in the developed countries it is doubling every 10-15 years. If one allows that all of mankind would need for showering the population as much energy as is extended in the developed countries, then the worldwide demand for energy would triple. But already in production in ground conditions such a quantity of energy due to combustion of fuel causes a danger of irreversible effects on the climate of the planet ("thermal contamination").

The utilization of solar energy in outer space has basic advantages in comparison with catchment of ground assemblies primarily due to the increase level of the flow of solar energy and the possibilities of a continuous process of energy production. As a result of this, the SSPP, in comparison with the ground assemblies, in 24 hr can collect 6-15 times more solar energy.

The planned appearance of the SSPP, usually considered as dis- /11 tributed in a geostationary orbit, at the present time, is basically determined. It is a distributed large-dimension structure whose basic element is solar batteries. The electric current developed is transformed into high-frequency radiation (SHF-radiation) transmitted to Earth where the inverse transformation of SHF radiation to electric current of the required parameters takes place. On its own scale the SSPP is a grandiose structure. The use of a photoelectric method of direct conversion of radiant energy of the Sun to electrical, on the basis of semiconductor solar elements with efficiency 10-20% results in the necessary catchment of a large quantity of radiant energy and, correspondingly, to the large area of the solar batteries.

With the useful power of the SSPP 5 GW, the dimensions of the solar collectors amount to 5X10 km, that is, their area equals 50 km^2 and the weight of the SSPP in working orbit is evaluated as 20 to 60 thousand tons depending on the design improvement of the energy assembly and the system of controlled transmission of energy from space to Earth. If the delivery of the elements of such a SSPP in geostationary orbit is accomplished using the TSS on a LPRE base, then the total mass in the reference near-Earth orbit, along with the fuel for interorbital transportation amounts to 100-300 thousand tons. According to some calculations, for assembling the SSPP in space using automated methods one would need about 500 persons for 6-12 months.

Space conditions for assembly in many relationships are ideal. Loads on the structural elements in weightlessness are insignificant due to the absence of atmosphere one eliminates the effect of wind load unfavorable meteorological conditions and the work can be carried out continuously. Two variations for assembling the SSPP are basically possible: in the reference near-Earth orbit (for example, at an altitude of 500 km) or directly on the geostationary orbit. In the low orbit it is more expedient to assemble the small elements of the structure with subsequent transportation of them into geostationary orbit; then they themselves can provide the necessary electric power. In the /12 opinion of specialists, even in the first decades of the coming century, it is possible to put into space standard SSPP for the electric power supply from Earth with a transmitted power up to 5 GW.

The question "How much is it necessary to do?" rests on the economic indices of the SSPP. With the contemporary level of technology, specific expenses in the production of electrical energy using the SSPP even somewhat exceeds the cost of a single kilowatt of energy obtained in a thermal or atomic power plant. One needs only to find methods for a significant decrease in the weight of the space electric power plant while retaining its useful power and also the quality of the new principles for solving transport problems. The latter includes providing delivery of cargo into reference near-Earth orbit with minimum cost and minimum loss for the environment and an organization of optimum transfer of these loads into geostationary orbit.

Predictions in the field of related branches of rocket-space technology make it possible to expect a decrease in weight and cost of the SSPP. For instance, in the last 20 years, the specific weight of solar batteries has dropped by 18 times and the cost by 20 times. And it is just the cost of the solar batteries and the expensive transporting them that make up a large part of the cost of the SSPP. One can expect that they will get even cheaper -- by some estimates, the cost of one kilowatt of energy of solar batteries by 1985 will be decreased by 10 times in comparison with the 1980 level. When transferring to thin-film batteries their weight in the future can drop 50 times.

As to transportation means, during production of electric energy in space commensurate with scales for its worldwide production, one needs to put into orbit around Earth many millions of tons of structures. It is entirely possible that one will need a transfer from traditional thermal chemical methods for creating thrust (LPRE), for a new more effective energy for the future TSS.

Transport problems of space production. In the future there are three basic approaches to the development of space production: production in space of new materials with improved characteristics and also substances which are impossible to obtain on Earth; the removal /13
of types of production which are particularly harmful for the environment into near-Earth space in order to protect the biosphere of Earth and avoid "thermal contamination"; the creation in space of the production of structural materials and elements for deployment of large-dimension structures (for example, the SSPP, large orbital antennas, etc.). Problems for space transportation have been formulated appropriate to this approach.

The production of new materials in space includes the use of special conditions of orbital flight in the production processes: long-term weightlessness, a surrounding deep vacuum, high and low temperatures and space radiation. The basic functions of the TSS come down to supply operations: delivery to orbital stations of the initial raw material and return to Earth of products produced in space. In the next decade, due to the high cost of space flights, it will be desirable to manufacture in space only unique costly products whose annual requirement is comparatively small (from a few hundreds of kilograms to a few dozens of tons).

For instance, the possibility is being considered of production in space of garnet crystals used in elements of the computer memory in order to improve their characteristics. According to an evaluation by foreign specialists, the needs for these crystals will be characterized by a cost of more than 1 billion dollars. And if space production can cover part of this demand, then there will be a perceptible savings in means. When production of some materials is successfully set up in space (for example, new superconducting alloys with improved critical temperature or high-quality glass), then this will precisely revolutionize the new branches of engineering.

Experiments directed at organizing production in space of new or improved medical-biological and pharmaceutical preparations are receiving a good deal of attention. According to estimates of foreign specialists, by the year 2000 in space 30 tons of biological preparations will be produced per year (enzymes, vaccines, etc.) whose total cost will be on the order of 17 billion dollars.

Besides the production of new materials, the future industrial /14
conquest of space involves the all-purpose concern of scientists in changes in the ecological circumstances on Earth which have occurred due to the effect of industrial activity of man. In the first place, when the cost of space transportation is somewhat decreased, in space it will be expedient to introduce those types of production which are dangerous for mankind. It is proposed that harmful waste material from production outside the limits of the planet will go into the natural flow of space processes (radiation, magnetic, etc.) and will not "stop up" outer space. In other words, putting waste materials into space is essentially returning them to their natural element. However, the question requires further all-purpose study.

The development of outer space includes the prospects for using not only external sources of energy (mainly, solar) but also the extra-Earth raw materials, for example, the useful minerals of the Moon and materials of asteriods. The demand for this involves first of all solving large-scale problems in near-Earth space (deployment into geostationary orbit of SSPP, large orbital complexes, etc.) and is dictated by expressions of an economic and ecological character. In this case, the necessity no longer arises for taking from Earth large useful loads but one needs to create special space complexes for delivery and reworking of, for example, lunar raw material and effective means for transporting it.

From the lunar rock, as study of their composition has indicated, one can obtain metals, metal ceramics, fiber and crystal and composition materials, devitrified glass and special glass, powder-type structural materials, and also oxygen which can be used for TSS in life support systems and as a fuel component (oxidizing agent).

The concept of large-scale space production complexes and the transport needs can be obtained from evaluations published in designs for the SSPP. For instance, in the case of producing panels and solar batteries in orbit (their weight amounts to 50% of the weight
of the SSPP) for deploying the SSPP demonstrated with power 30 MW on /15
a geostationary orbit, one needs an experimental factory with four production lines (each weighing up to 100 tons and productivity 1200 m^2 per day with a total number of service personnel 50 persons). For deployment of a system from the SSPP with power of 5 GW, one needs a full-dimension orbital factory with 16 production lines, each weighing about 200 tons and productivity 8500 m^2 per day) with personnel numbering 210.

Ways of Improving the TSS

Modern TSS: achievements and flaws. First of all going on to a prediction of a development of the TSS in the future, let us look at the achievements and flaws of existing transport equipment -- traditional rocket-carriers and booster space stages. In the first years of conquest of space only the USSR and USA produced the necessary rocket-space technology. According to the degree of accumulation of the scientific-technical work and production capabilities for it, then the following countries joined in: France (1965), Japan, the Chinese People's Republic (both in 1970), Great Britain (1971), and India (1980).

Among the rocket carriers developed in the USSR and distinguished by high mass-energy characteristics and reliability, one should note the following: the Vostok, Kosmos, Proton and the rocket-booster of the Soyuz spacecraft. In the USA, also a system of rocket boosters was developed the majority of which are modifications of the combat ballistic rockets such as the: Atlas, Thor, and Titan used as primary stages. Superpowerful space boosters of the Saturn series were developed.

The multiplicity of types of rocket boosters designed with load capacity from a few hundreds of kilograms to more than 100 tons and also experience in their operation have made it possible to trace progress in achievements and improvements of characteristics of rocket boosters and at the same time flaws present in this transport means. For the period of development of the TSS, their load ratio to payload was increased. While the first high-altitude meteorological rockets expended many hundreds of kilograms of fuel per each kilogram of payload, the Scout rocket of the 1950's expended 115 kg of solid /16 fuel per kg of payload put into orbit and the Saturn-5 rocket carrier decreased fuel consumption to 20 kg per 1 kg of payload.

The improvement and characteristics of the rocket-booster were possible due to transfer to more effective rocket engines and the design-mass improvement of rocket stages. For instance, the liquid propellent rocket engine for the Fau-2 rocket on oxygen-alcohol fuel developed a specific pulse (that is, the ratio of thrust of the total weight of the working substance expended per unit of time) of 280 s whereas the modern LPRE on oxygen-hydrogen fuel in vacuum conditions provides a specific pulse up to 455 s.

The weight of the Fau-2 rocket structure including the housing, fuel tanks, pumps, rocket engines and other parts amounted to about 25% of the full weight of the rocket. Achievements in the field of creating light rocket structures made it possible to reduce the relative weight of the structure of the rocket stage to 7.6%. The cost indices were improved considerably. For instance from 1958 to 1978, the cost of just putting the payload into a low orbit for an AES was decreased in the USA from 80 thousand dollars to 5000 dollars per 1 kg.

Nevertheless, the characteristics and conditions of operation of the rocket carriers is far from being perfect. The factors which prevent a wide use of rocket-space technology continue to be the high cost both of the means for delivery and the payload itself as well as the necessity for involving large production power for manufacturing them. Moreover, during operation of modern rocket-boosters one needs to have a right of way, that is, an area free from shipping on the water area of the world's oceans or unused territories of dry land intended for dropping the used stages; with time this becomes more and more difficult due to the intensively developed economic activity of man who has taken over all the new territories.

Another problem is clogging near-Earth space with used upper stages of rocket boosters and spacecraft which have completed their time period for active existence. At the present time, in space, /17
there are several thousand such objects; their number is increasing and the increasing contamination of space is beginning to cause concern. The dense layer of atmosphere in which they burn up protects us from falling remains of such space objects. But they can become dangerous for aviation, especially for supersonic transport jet aircraft flying at high altitudes (up to 18 km) where the kinetic energy of incident debris is not yet successfully dissipated.

Special observations are made of incident space objects. Upon decision of the UNO, the governments which launch AES are obliged to take financial responsibility for possible damage and destruction of different objects on Earth and in the air from collisions with parts of rockets and satellites dropping from space. It is possible that in the future international agreements will be made obligating the governments which have launched the spacecraft releasing them from the rocket stages developed and the objects of orbit suitable for flights of manned space stations.

It is proposed that these problems can be partially solved by returning the rocket stages and the spacecraft to Earth.

<u>The concept of frequency and questions of profit</u>. The idea of the repeated use of rocket systems is not new. It is mentioned in the works of the founders of cosmonautics, K.E. Tsiolkovskiy, F.A. Tsander, Yu.V. Kondratyuk and also the well-known foreign specialists H. Obert, R. Goddard and others. However, the introduction of reuse involves additional energy-mass consumption and the solution of a number of technical problems, in particular, the creation of reuseable rocket engines, multi-use heat protection for the upper stages which would be difficult to realize in practice in the initial stage of designing rocket-space equipment.

Seriously, the questions of reuseability began to be discussed in technical literature in the 1960's. Numerous foreign projects of reuseable TSS with a technical-economic basis for their use showed that effectiveness of such systems significantly depends on the technical level of development at conditions of operation. Then their /18
use can have an effect only when propagating the principle of reuseability (repeated use) and the payload carried. The complexity of the concept of reuseability and insufficiency of its economic base at this stage were confirmed in the process of realization of the

American design of a reuseable transport spacecraft (MTKK [Mnogorazovyy transportnyy kosmicheskiy korabl', RTSC]), the Space Shuttle.

The attempt to complexly solve the problem (decrease specific expenditure for putting into orbit and providing the possibility of returning the payload for second use) led to the necessity to include in the TSS a returnable manned spacecraft made according to an aircraft diagram. The RTSC is put into orbit using two solid-fuel accelerators of the first stage and a hydrogen-oxygen second stage; then the basic engine assembly of the second stage is shifted to the orbital craft (or orbital stage).

The first stage accelerators, after completion of work, are separated from the second stage; passive flight occurs on a ballistic trajectory and descent by parachute to the ocean. Then they are towed to the shore and delivered to the service base for restoration and repeated use (up to 20 times). The fuel compartment of the second stage is separated from the spacecraft not long before exit into orbit and it falls into the ocean being destroyed when entering the dense layers of atmosphere. The orbital spacecraft after leaving orbit and slowing down in the atmosphere completes an aircraft landing at a special airport.

It is proposed that one RTSC be used for at least 100 flights with replacement of separate elements during operation (engines, heat shield plates). Such a TSS with a launch weight of 2000 tons provides entry into low near-Earth orbit and return from orbit to Earth in the cargo compartment of an orbital spacecraft (length 18.3 m, diameter 4.6 m) of the payload weighing, respectively, up to 29.5 and 14.5 tons.

Development of the RTSC has run into a number of difficulties of a technical and technological nature. One of these was involved with the creation of tile multi-use protection of the orbital spacecraft. It was necessary to cover the housing of the orbital craft (and it has /19
a fairly complex shape) with several tens of thousands of heat protecting tiles of various dimensions and thicknesses (the heating temperature of the spacecraft at different points during launch and braking in dense layers of the atmosphere changes from several hundred to one and a half thousand degrees Celsius). Another complication includes the creation and development of highly reliable cruise oxygen-hydrogen engines of the second stage with an improved safe life (calculated for 55 flights).

The development of the plan took 10 years; the first test flight was postponed for three years and took place in April 1981. In the two and half years since the first launch 8 flights have been accomplished. In the first place, the planned rate of launches with standard operation envisaged 60 launches per year.

Costs for putting payload into orbit were not significantly decreased and this was basically what had been hoped for by the developers of the RTSC. The stated cost at the beginning of the development for launch of the spacecraft was 10.5 million dollars and in the past decade this is increased by several times. However there remain in operation the single-use rocket boosters, the Scout, Delta and the Atlas-Centaur, which were to be replaced by the new TSS. The necessity for putting a large passive mass of an orbital spacecraft, besides the payload, into orbit significantly increased the launch weight of this TSS in comparison with that of the rocket booster with the same load lifting capacity. According to an estimate by American specialists, the Space Shuttle RTSC, as a system for putting objects into orbit was not as good in total cost for transport as the new (that is, that develops simultaneously with this technological level) single-use rocket booster.

The basic economy in means from using the RTSC was to be obtained by decreasing the cost of the payload. This so-called "effect of the payload" is related to the possibility of putting into orbit or returning to Earth the preventive, repair-recovery and other work on servicing the payload which increases the time period for its active existence and decreases cost of the space program as a whole. Then, it is proposed that the module principle be widely used with the development of payload for construction using unified systems and assemblies.

However, transfer to a new adaptation for servicing of the payload also involves additional expenditure of means and time. Then, due to the limited maneuvering possibilities in space of a heavy orbital craft, only objects located at low near-Earth orbits can be serviced. For servicing of payloads at high orbits, and in the future, in the opinion of a number of specialists, up to 50% of all payloads will be in geostationary orbit necessary for the development of reuseable interorbital tugs. /20

In this way, the creation of economical reuseable TSS at this stage is a complex problem and right now it is difficult to judge how effective it is in relation to the Space Shuttle RTSC. It is only possible to note that mainly the advertising statements about profitability and universality of use of the RTSC which came out at the beginning of its development were very optimistic; they have changed to more sober and conservative estimates of the scale of its use. For instance, while earlier they were talking about a program of 725 flights for the Space Shuttle, planned 12 years ago, this number has been cut down several times since then. At the present time, it is planned that there will be only 311 flights of the RTSC before 1994.

The system of the American RTSC selected is a compromise not only in the plan for reuseability. The use as the first stage of two solid fuel boosters facilitates an increase in reliability of the system and safety of the crew but at the same time leads to the danger of contaminating the atmosphere with products of combustion of a solid fuel including ammonium perchlorate, polybutadiene and aluminum additives. From the moment of launch of the RTSC to an altitude of about 40 km (completion of operation of the boosters) in the ambient space several hundred tons of combustion products are ejected including such toxic components as particles of aluminum oxide, carbon monoxide, gaseous hydrogen chloride, etc. The harmful effect of the products of combustion can include toxic contamination of the cloud cover resulting in the fall of acid rain and unpredictable changes in the weather.

Danger of another type exists -- a breakdown in the stratosphere /21
ozone layer under the effect of chloride compounds, that is, the formation of the so-called "window" in the ozone layer. As is well-known, this layer protects all living things on Earth from lethal ultraviolet rays emitted by the Sun.

Of course, one must say that all these defects and the compromise character of the American TSS based on the Space Shuttle RTSC, mainly was predetermined by the militaristic essence of this program. Inasmuch as a significant number of RTSC launches right now is designed for purposes of the Defense Ministry of the USA, the developers of the American reuseable spacecraft have encountered pressure from the Pentagon which is trying as rapidly as possible to introduce this TSS into construction even taking into consideration its design defects.

In any case, at the present time, the study of ways of improving the TSS are continuing.

<u>Improvement of rocket engines, design and control systems of the TSS</u>. In the recent past, development of the rocket-space technology has reached a high level in the characteristics of the LPRE. On an example of the engine for the second stage of the RTSC Space Shuttle, one can note that the specific pulse of the cruise engines with oxygen-hydrogen fuel in a vacuum is 455 s. The engines have a broad range of thrust adjustment and are calculated for a total operational life calculated for tens of manned trips. Significant successes are achieved in parts of control systems and diagnostics of operation of the engines which considerably increased reliability and safety of their operation. For control of operation of the engine, the onboard computers were used.

Along with a further increase in characteristics of the LPRE on oxygen-hydrogen fuel, recently, in foreign engine construction a good deal of attention has been devoted to studying the possibilities of two-fuel engine units (DU [Engine units, EU]). In the EU, it is proposed that one use with a single oxidizing agent (oxygen) two types of fuel -- hydrocarbon and hydrogen which makes it possible to realize jointly the advantages of the fuel with hydrocarbon (high density, low mass of the EU) and the advantages of fuel with hydrogen (high specific pulse). The most effective is use for both types of fuel of /21
the same engine in which sequential treatment of the fuel is planned (first the hydrocarbon and then the hydrogen).

Figure 1 shows the relationship of the relative weight of the load to the required increment of speed for a two-fuel and for traditional engine units.

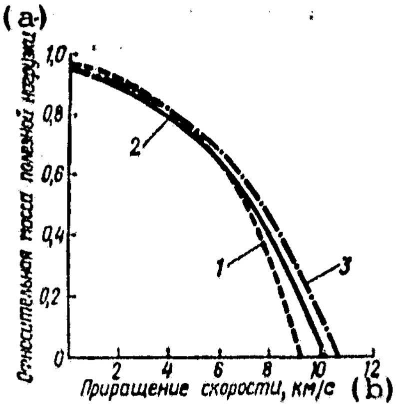

Figure 1. Dependence of the relative weight of the payload on the required increment of speed for the two-fuel and the traditional EU: 1 -- only hydrocarbon fuel; 2 -- only hydrogen; 3 -- sequential processing of the fuel through a single engine.

Key: (a) relative weight of the payload; (b) increment of speed, km/s.

Thanks to the lower relative weight of the EU for fuel with hydrocarbon (1) with small increments of speed, such a fuel is more suitable; however as one increases the necessary increment of speed the hydrogen fuel becomes more effective (2) thanks to the significantly large specific pulse. The slant of curves 1 and 2 changes in using hydrocarbon fuel beginning with the increment of speed exceeding approximately 2 km/s.

Relationships are given without taking into consideration the loss of speed for overcoming gravitational forces (it is calculated only for an ideal speed). One should note that in the initial phase of flight using hydrocarbon fuels, due to the low specific pulse, one needs a considerable consumption of the fuel components and this involves the fact that other conditions being equal, there is an increase in the acceleration of the spacecraft and consequently a decrease in loss of speed and overcoming gravitational forces. This is an additional argument for the use of two-fuel engine units.

Another reserve in improving the characteristics of future TSS is their further design-weight improvement. Potential possibilities for decreasing the weight of the design are determined by using new materials and the adoption of different design solutions and also the improvement of design methods. It is expected that adhesive compounds will be /23
more and more widely used (in order to decrease the weight of the attached components). Besides the development of new metal alloys with improved strength in operational indices, more and more composition materials are being used based on polymers and metal bonding components reinforced with high-strength fibers made from boron, coal-graphite, monocrystalline fibers, etc.

According to the estimate of foreign specialists, the advantages of designs made from promising composition materials for the design of aviation and spacecraft from glass fiber and aluminum, in their special features, are apparent when using them in those situations where a low coefficient of temperature expansion, lightness of the structure, high rigidity of its spatial structure and thermal insulation are all required. Multipurpose studies for improving production processes for their manufacture, decreasing cost and, moreover, a thorough analysis of the effect of conditions of loading and the environment on the characteristics of the safe life are all necessary for the widespread use of composition materials in space technology. According to this evaluation, the composition components can be 25-30% lighter than aluminum components.

There are possibilities for improving the heat protecting systems. Reuseable ceramic shields used on the American RTSC withstand adequately high heat temperatures; however, there exist a number of disadvantages: brittleness, the capability of absorbing moisture and labor consumption when preparing and servicing them. In relation to this, attention is given to metal heat protecting systems with limited use of active cooling. In such heat systems, thanks to circulation of the heat carrier it is selected from sections of the surface with high heat temperature (for example, the leading edges of the wing of an orbital spacecraft) and is transferred either to a special radiator emitting it into the ambient atmosphere or to a section of the surface with relatively low temperature which takes the role of radiators.

A decrease in weight can be achieved when transferring to a new design for fuel compartments, combining in it the properties of load bearing structures and heat insulation of cryogenic fuel. The storage of cryogenic components onboard on the TSS, for example, liquid hydrogen and liquid oxygen, is possible only by creating special types of heat protected structures. Here special difficulties are caused by the use of liquid hydrogen as a result of its low boiling temperature (20 K) and low density (71 kg/m^3) which results in the creation of tanks with large volumes with large surface area. Damage to the heat insulation of the fuel compartment results in penetration of moisture and air into it which condenses and freezes forming a certain vacuum in the penetration zone. Then new portions of air penetrate and in the final analysis, a thermal bridge is formed, that is, a connecting piece between the cold wall of the fuel compartment and the heat of the ambient atmosphere. The powerful thermal inflow into the tank results in intensive boiling of the fuel components.

One of the variations for the perspective structure which combines the functions of the power structure, the heat shield and heat insulation is shown in Figure 2. It is expected that such structures will have a small specific weight, will be simpler and technologically feasible, and will have good resistance to acoustic load. But broad scientific-research and test-design work in a number of aspects must precede their use: an evaluation of the compatibility of structural materials with cryogenic components and their behavior in low temperature conditions under multiple loads; the development of structures with a minimum coefficient of heat conductivity; development of methods for decreasing temperature stresses; preparation of samples for perspective designs, and also full dimension models with testing of all their aspects.

The control system plays an important role in optimizing designs and improving perspective TSS. Recently, besides the traditional systems for control, active systems have also begun to be used. The use of active systems for control makes it possible to decrease in flight the wind and aerodynamic loads, to decrease weight, increase flight qualities and improve controllability, expand the field of flight regimes for the projected articles (due to development on board of the so-called adaptive programs for flight). Development of active systems for control became possible thanks to the use of electrical (remote control) systems for control of flight inasmuch as they make it possible to widely use the onboard electronic computers (BEVM [Bortovaya elektronnaya vychislitel'naya mashina]).

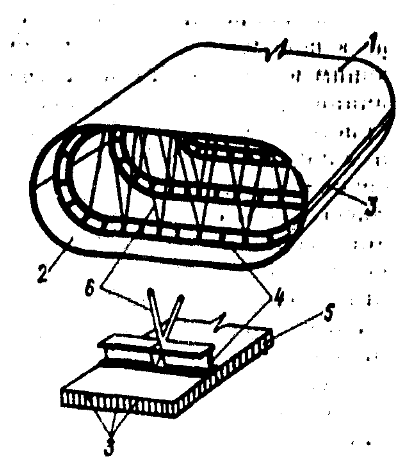

Figure 2. One of the variations of a promising structure which combines functions of the power structure, heat shield and heat insulation: 1 - sheathing of the upper surface made of titanium alloy; 2 - sheath of the lower surface made of special heat-resistant alloy; 3 - slots for compensation of temperature deformations; 4 - frame; 5 - honeycomb; 6 - rod elements.

The circle of problems solved by control systems continues to expand. For perspective TSS, the use of control systems is considered not only for providing flights for energetically optimum trajectories and for decreasing flight loads, but also for automating the prelaunch preparation, launch and planning of flight programs (including operations for maneuvering, approach or docking in space, servicing of payloads). In connection with this, the necessary memory capacity and fast action of the onboard computer is increasing (Table 1).

In general, the perfection of the onboard computer at a given stage includes the module principle of construction based on using standard units; the multiprocessor structure, the use of modules for a certain function use, expansion of the command system, the microprogram (flexible) control; insensitivity to failure due to the use of reserve equipment and the capability to readjust the logic structure of the onboard computer during failure; the broad use of large integral systems.

And finally, one should note the /26
improvement of the methods themselves for optimum planning which have been widely used on the basis of mathematical programming and the use of fast-acting computer equipment. In the future these methods will take into consideration the demands for reliability, the stochastic nature of external effects and the nonstationary quality of limitations improved methods of calculation and better understanding of physics of the phenomena make it possible to decrease the reserves for strength, stability and controlability, etc. for designing future TSS and at the same time this will make their structures lighter.

Requirements for TSS. The prospects for mastering near-Earth space and the problems related to the operation of modern means for putting SC [spacecraft] into orbit make it possible to formulate the general requirements for the TSS of the future.

Table 1. Characteristics of Promising Onboard Computers for Space Use (According to an Evaluation by Foreign Specialists)

(a) Характеристики	1980 г.	1985 г.	1990 г.
(b) Производительность одного процессора, млн. операций в 1 с	2,5	6,3	14,4
(c) Емкость запоминающего устройства, бит/кристалл	500 тыс. (d)	20 млн. (e)	800 млн.

Key: (a) Characteristics; (b) Productivity of one processor, millions of operations per 1 s; (c) capacity of the memory device, bit/crystal; (d) thousand; (e) million.

It is proposed that deployment into space of large-dimension structures will result in a large number of unitypical elements, units and components whose manufacture is possible directly on location on the OSS from semimanufactured goods delivered from Earth (for example, rolled metal strips wound on a bobbin). Transportation of raw material and prepared products from space production is possible in containers with adequate tight packing. Therefore, the volume and mass of the modulus of payload are not limited for future TSS.

The requirements for the TSS for high productivity (the value of the load flow realized per year) and the relatively low specific cost in transportation are more important from the point of view of efficiency and profitability in the decisions of large-scale long-term problems in space (deployment of the SSPP [Satellite Solar Power Plant] heavy orbital complexes for industrial use, etc.). For instance, when /27 deploying systems made up of standard SSPP with power 5-10 GW, the average annual load flow for a low near-Earth orbit will be measured in hundreds of thousands of tons and the necessary specific costs for transportation, starting with a profitability of the SSPP must be decreased by more than a magnitude according to estimates of specialists.

One should also note the expediency of separating the TSS into purely cargo and passenger (then for a portion of the former there will be the basic load flow in space). Removal of limitations applied to the presence of humans on board makes it possible to expand the search for new more effective principles for putting payload into AES orbit. At the same time, the passenger TSS designed for delivering a limited number of specialists into space basically for accomplishing assembly operations, monitoring and control, repair and prophylactic work, can be realized on the basis of traditional means for injection.
One should not exclude in this approach the search for more effective and profitable TSS, for example, when organizing space settlements, but these means according to conditions of comfort and safety will naturally differ from the long-term cargo TSS.

And finally, the requirement for delivering cargo to reference near-Earth orbit with minimum loss of an ecological character is unchanged for all future TSS. With large scale use of prospective TSS, one must not contaminate the atmosphere of Earth with harmful products of fuel combustion, exceed the allowable standards for acoustic load, eject in flight or leave in orbit separate elements of the structures.

Transport Means in Industrial Space

The capabilities of prospective TSS with liquid propellent rocket engines (LPRE). In the plan for the general requirements for the TSS of the future, let us look primarily at the capabilities of the prospective TSS based on LPRE. The thrust systems on a LPRE base have been used successfully for some time for studying and mastering outer space. It will not be an exaggeration to say that in the con- /28 cept of most nonspecialists the LPRE is hardly the only means for creating thrust in space. However, this is far from being so. The transportation systems on the LPRE, in spite of the possibility of improving them, are limited in energetics. It is easily confirmed here if one turns to the well-known formula of Tsiolkovskiy which defines the increment of flight velocity of the rocket ΔV in a vacuum in the absence of the force of gravity as: $\Delta V = W \ln Z$ (W is the rate of discharge of the working substance, Z is the ratio of the initial mass of the spacecraft to the final mass when all of the onboard reserve of working substance or part of it has been used up; the so-called Tsiolkovskiy number).

The maximum value of the rate of discharge of the working substance for the LPRE amounts to about 5 km/s. The increment of the velocity of the rocket depends also on the ratio of its initial and final masses. In modern rocket boosters with LPRE the portion of fuel can be up to 85% of the launch mass. A simple calculation shows that a single-stage craft with LPRE then has an increment of velocity which does not exceed 9.3 km/s, that is, the maximum energy capabilities of such a craft provide putting it into only a low near-Earth orbit. Naturally the use of principles of multistage operation expands its capabilities but this makes the space flights more expensive and complicated and as has already been said above, leads to contamination of space by the stages used if they fail to return.

In this way, the attempt in the future to maximally simplify and cheapen the TSS on LPRE, that is, to transfer to an ideal single-stage system, leads to controversy with the energy capabilities of such systems for which, from the point of view of increasing the mass output, the use of multistages is necessary. Then, the effect from the design improvement of the TSS expected in the future, as a rule, dampens the additional consumption of mass to provide return and repeated use of the TSS which is dictated by economic or ecological considerations. Numerous designs for TSS with an LPRE base published right now in the foreign press are themselves an attempt to find such a compromise technical solution.

Basically this single or two-stage vehicle has an aerodynamic or /29
ballistic system (Figure 3a, b). The aerodynamic system is considered for manned TSS with relatively small payloads (for this, comfortable conditions for return are characteristic -- descent with small acceleration factor and airplane landing), a ballistic system -- for heavy cargo unmanned TSS (it provides a large mass output for payload, that is, the ratio of the weight of the payload to the launch weight of the TSS). However, as a whole, the weight output of future TSS based on the LPRE is not higher than the nonreuseable rocket-carrier and amounts to a few percent of the launch weight, that is, when putting modules of payload weighing from a few tons up to a few hundreds of tons into orbit, the launch weight of such TSS amounts to thousands of tons.

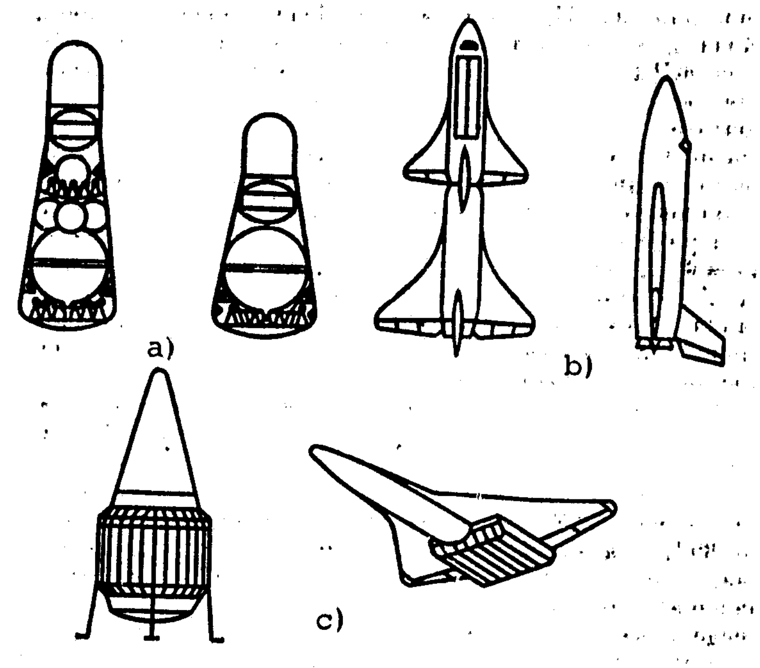

Figure 3. Diagrams of prospective single or two-stage TSS on an LPRE base: a) ballistic, b) aerodynamic , c) using the VRD [air rocket engine].

One should note that the specific indices of prospective TSS based on the LPRE (according to mass output and cost of putting into orbit) are improved with an increase in scale, but due to limitations caused by existing standards for acoustic load, sharply increase with an increase in the launch weight of the TSS; the maximum value of payload put into orbit cannot exceed 500 t.

In order to improve the power characteristics of the TSS based on chemical rocket engines, plans are being considered for launch systems using combined DU which put together into a single assembly rocket and turbojet or ramjet engines. The proposed effectiveness of using combined DU is explained by the fact that turbojet and ramjet engine assemblies have a specific pulse 8-20 times larger than the LPRE (calculated starting with the consumption of fuel stored on board the vehicle). The use of more effective, although heavier DU per section of acceleration in the atmosphere (that is, the use of external resistance of the atmosphere, in this case, the air is the oxidizing agent and the working substance) is attractive especially for single or one and half stage TSS. As estimates show, the relative mass output for payload in such TSS can be increased by 7-8%. Then, the type of launch can be either vertical or horizontal (Figure 3c).

And all of the future TSS based on the LPRE, in spite of the possibility of decreasing specific costs for going into orbit by several times (the cost of putting 1 kg of payload into orbit) continue to remain fairly complex and cumbersome systems for realizing large-scale cargo flow (for example, for deploying SSE in geostationary orbit). If we use a nominal value of load capacity of the future super-heavy carrier as 250 t, then the creation of the first standard SSE weighing 40 thousand t in geostationary orbit (correspondingly, 200 thousand tons for a low near-Earth orbit) when using interorbital transport vehicles based on the LPRE, one requires 800 launches and then about 5 million tons of rocket fuel will be used up. Such a program of /31
launches is maximum for a carrier and similar SSE require tens and hundreds for providing the power necessary on the scale for the entire Earth. Intensive flights of super-heavy TSS based on the LPRE with consumption of hundreds of millions of tons of fuel will be accompanied by significant thermal ejections into the atmosphere which is fraught with serious ecological disturbances.

The space transport with nuclear energy. An important approach in the field of increasing energetics (load ratio) of the rocket booster is transfer to higher efficiency rocket engines, for example, nuclear. Then, the number of launches of the rocket-boosters and the total consumption of fuel can be decreased when solving future space problems.

In the LPRE, the discharging working substance is formed due to fuel combustion. Then the composition and temperature of the combustion products and, in the final analysis, the specific pulse, are determined by the properties of the fuels used. In distinction from this, in a nuclear rocket engine (YaRD [Yadernyy raketnyy dvigatel', NRE]) for heating the work substance one uses heat generated in the nuclear reactors. The energy source and working substance are separate here. As the working substance hydrogen is preferable; it has the highest value of gas constant which determines, besides temperature and degree of expansion of the nozzle, the specific pulse of the engine.

When heating hydrogen in a nuclear reactor, the specific pulse basically depends on the temperature in the active zone. Depending on the phase state of the substance of the active zone, the NRE is divided into solid-phase, liquid-phase and gas-phase. The greatest interest is in the solid-phase NRE (according to depth of processing and technical stock) and the gas-phase NRE (for high specific index). As an example of a solid-phase NRE one can use the engine developed at the beginning of the 1970's in the USA in the Nerva program (the thrust of the engine was 330 kN, specific pulse 825 s).

The maximum specific pulse of the solid-phase NRE is limited to melting temperature of the separated substance and can amount to 900 s which is twice as large as in the best modern LPRE. However, the advantages obtained from this increase in specific pulse are decreased due to the increase in weight of the TSS structure based on the NRE; this is due to the presence of a nuclear reactor, radiation protection of the crew and payload and finally, the massive heat-insulated tank containing the reserve of liquid hydrogen. For rocket stages with /32
LPRE on oxygen-hydrogen fuel, the ratio of the weight of working substance to the weight of the structure is within limits of 7-8, whereas for stages with NRE this parameter is decreased to 3-5.

This is why, in spite of the stock in the field of solid-phase NRE and the possibility of their practical realization, a good deal of attention from the point of view of creating prospective TSS involves the gas-phase NRE, whose specific pulse can reach 2000-2500 s. These NRE still existing only in plans, do not differ from the basic principle of action from the solid-phase NRE but due to the fact that during their work, the substance of the active zone of the reactor is found in a gaseous state, it is possible to considerably increase heating temperature of the working substance and, consequently, the specific pulse. There are advantages in this but correspondingly their creation requires solving more complex technical problems.

With the heat temperatures of the working substance on which the gas-phase NRE are calculated, the nuclear fuel is in the reactor in the form of plasma under high pressure (500-1000 atm), otherwise the density of the generated substance will be too small in order to provide critical load of the reactor. Therefore, it is necessary to create a high-strength design for the engine. Another difficulty is the problem of separation of the nuclear fuel from the heated working body and the active zone of the reactor. The most promising in this approach is the gas-phase NRE with magnetic maintenance of the nuclear fuel. It is proposed that the gas-phase NRE with magnetic maintenance of the nuclear fuel will have a thrust in a range from a few tens to tens of thousands of kilonewtons providing adequately high thrust-equipment of the TSS.

However, a common problem in the use of TSS based on the LPRE continues to be providing radiation safety. The operating NRE is a powerful source of gamma and neutron radiation. Under the effect of radiation one can produce a heat of the work body and the structure which is not allowable, embrittlement of metallic and breakdown of plastic articles, a breakdown in insulation of electric cables and electronic equipment going out of order; but the main problem is radiation damage of the crew (Figure 4).

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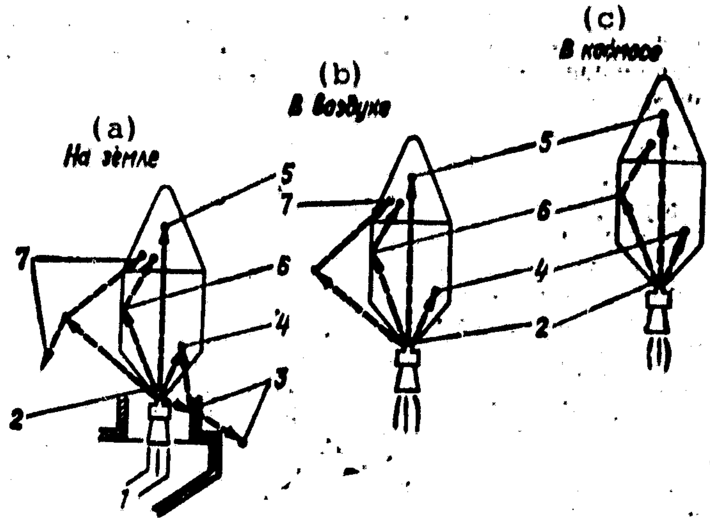


Figure 4. The character of radiation danger during operation of an NRE: 1 - effect of reactive exhaust stream; 2 - radiation damage to the TSS structure; 3 - activation of the launch device; 4 - heating of the working substance in the tank; 5 - direct propagation of radiation in the compartment of the payload by scattering in the structure (6) and by scattering in the air (7).

Key: (a) on the ground; (b) in the air; (c) in space.

The greatest radiation damage during operation of the TSS based on the NPRE is during ground launch and flight in the atmosphere. In conditions of open space one can use the so-called "shadow" shield as the barrier which guarantees protection of the crew only in a space vacuum where there is no scattering of radiation from the air. For TSS launched from Earth it is necessary to have a very heavy circular shield. Always the danger of radiation damage during operation of such TSS exists because of the incoming radiation on the structure, the radiation of the reactor after switching on the NRE, possible contamination of the atmosphere, etc.

In all likelihood, the TSS based on the NRE will be used outside the atmosphere of Earth -- in interorbital transportation operations, when delivering heavy cargo to geostationary orbit, in load operations on the "near-Earth orbit -- Moon" route. There are great possibilities /34
open to the TSS based on the NRE in interplanetary flights.

Looking at the use of nuclear energy in space transportation one should particularly note the possibilities of creating in the future a thermonuclear rocket engine (the TYaRD [Termoyadernyy raketnyy dvigatel', Thermonuclear rocket engine, TNRE]) which is a basically new step in the path of development of space thrust systems. According to a preliminary evaluation, the TNRE with thrust of several thousands of kilonewtons is capable of reaching a specific pulse of 18,000 s which is more than 30 times larger than the specific pulse of prospective LPRE. The relative load capacity of the TSS based on the TNRE is raised ten times in comparison with the existing system.

The plans for the TSS based on the TNRE mainly are stimulated by work on mastering thermonuclear energy made over the last few decades. The indicated work, in turn, was directed at creating controlled thermonuclear reactors in which the original initiating heat of the reacting substance is considered (heavy isotopes of hydrogen -- deuterium and tritium) up to a temperature of several millions of degrees. This temperature must correspond to an energy adequate for nuclear fusion as a result of which a tremendous amount of energy is generated by thermonuclear synthesis.

In truth, one could say that the use of deuterium-tritium fuel will be extremely convenient in future industrial thermonuclear reactors; this would hardly be suitable for the TNRE because during combustion of this fuel 80% of the energy would be fast neutrons which without hindrance would penetrate the plasma and cause heating of the TNRE structure thus limiting the value of the specific pulse. More suitable is a mixture of deuterium with a light isotope of helium (only 2% of the energy goes into neutrons). However, one encounters another no less complex problem: to accomplish this reaction one needs a temperature of even hundreds of millions of degrees.

Thus, the TNRE is still a fairly problematic arrangement, but the TSS based on it makes it possible for man in the true meaning of the word to become the owner of the solar system (therefore the thrust systems based on the TNRE we will discuss later in the section on perspective TSS for interplanetary flights).

<u>The TSS using electrorocket engines</u>. Along with the TSS with large thrust, but limited economy for consumption of fuel (the LPRE, NRE) rocket-space engineering has highly economical systems with low thrust based on electric rocket engines (ERD [Elektroraketnyy dvigatel', Electric rocket engine, ERE]). The first ideas on the use of electricity for creating a propulsion thrust was presented by K.E. Tsiolkovskiy in 1911 and for the first time in the world an ERE was built at the beginning of 1929 as proposed and directed by V.P. Glushko. /35

In distinction from the LPRE and the NRE in which the working substance (respectively, the gaseous products of combustion of chemical fuel and heating while passing hydrogen through a reactor) is driven off by discharge through a nozzle (where the thermal energy is converted to kinetic), in the ERE, the working substance is accelerated by means of electrical energy. Then the working substance and the source of energy are separate. Thanks to the intake into the ERE of a large quantity of energy for a small weight of the substance, one can obtain a specific pulse on the order of or exceeding that of the LPRE and the NRE.

The working substance in the ERE is plasma, that is, ionized gas producing an electric current. The plasma is released by electrodynamic forces occurring as the result of interaction of electric current passing through the plasma with a magnetic field created by the internal source or a current passing through the accelerator. Besides the plasma accelerator, in the composition of the ERE there is a system for supplying the working substance, elements of a system for commutation and conversion of current, a regulation system, etc.

The electric rocket engine assembly (ERDU [Elektroraketnaya dvigatel'naya ustanovka, Electric rocket engine plant, EREP]) includes, besides the ERE, a source of energy (a nuclear reactor or a solar battery can be used for this), a system for conversion of energy, a system for storing the working substance and a refrigerator-emitter. In distinction from the space DU with LPRE or NRE, the electric rocket engine plant is a complex power system combining highly efficient ERE and the powerful onboard power plant.

For supplying the ERE one needs sources and converters for electrical energy which have a large mass increasing with an increase in the necessary thrust and specific pulse of the engine. Therefore, /36
the ERE with launch mass possible at this time is a low thrust engine which, in the existing experimental models does not exceed tens of Newtons. Because the thrust created in the EREP is considerably smaller than the weight of the EREP on Earth, this engine plant can be used only as a space thrust system in weightlessness conditions (after introducing the spacecraft into AES orbit), effective for long-term flights. The EREP is characterized by high economy in consumption of the mass of working substance stored on board the spacecraft and with each space flight there exists an optimum value of effective rate of discharge. This property is the result of separation of the sources of energy and the working substance.

The EREP can expediently be used in flights requiring relatively large energy consumption and not limited to time: with transportation of large loads with low near-Earth orbit to geostationary or from orbit of an Earth satellite to near-Moon orbit to automatic stations during flight to distant planets. According to evaluations of specialists, the use of ERE in interorbital transport vehicles (MTA [Mezhorbital'nyy transportnyy apparat, Interorbital transport vehicle, ITV]) using a geostationary orbit, makes it possible to increase the load ratio of the vehicle according to payload up to 70% as opposed to 25% for the ITV with LPRE (with flight times, respectively, 170 days and 7 days).

The use of the ERE was especially useful for transporting SSE units to geostationary orbit during their assembly in a reference near-Earth orbit. In the first place, one will be able to use in the ERE solar energy developed by elements of the SSPP itself which they transport. Secondly, the ERE provides the possibility of transporting cargo with small acceleration acting on the units of the station. And this considerably decreases the requirements for strength for large-dimension elements of the SSPP and, respectively, for decreasing their mass.

A typical structural-arrangement diagram for the acceleration stage based on the EREP with a nuclear reactor-generator for electrical energy is shown in Figure 5. The stage is arranged in the form of sequentially connected compartments located inside a cone at the top of which is the reactor-generator (principle of beam construction). Following the reactor-generator and the "shadow" shield for its radiation, there are the converters of electrical energy and the ERE compartment. For ejecting unused thermal energy there is the refrigerator-emitter inside which is the compartment for the working substance. Further, the farthest away from the reaction-generator is the instrument compartment and the compartment for the payload. The beam construction of the stage provides minimum mass of radiation protection. /37

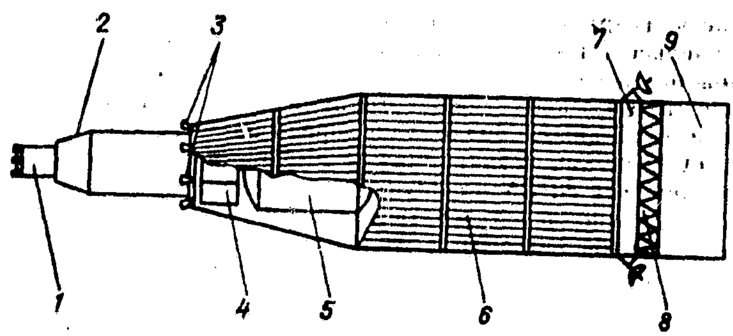


Figure 5. The structural-arrangement diagram of the acceleration stage with nuclear EREP: 1 - reactor-generator; 2 - "shadow" shield; 3 - ERE; 4 - converters for electrical energy; 5 - tank with working substance; 6 - refrigerator-emitter; 7 - instrument compartment; 8 - beam; 9 - payload compartment.

Figure 6 shows the typical diagram of the acceleration stage of the solar EREP of a panel type with film flat photoconverters. Structures supporting the converters are a flat panel with masts and slides. Between two such symmetrical panels is located a central unit including a system of tanks for storing the working substance, electric rocket engines, equipment and the payload. Between the solar batteries and the central unit there is a unit for commutation and a unit for converting electrical voltage. The central unit can be rotated relative to the solar batteries using the rotational drive. Then, the electrical current is fed to the central block through special slide contacts.

Also, solar EREP are being considered with parabolic concentrators /38 for solar energy and turbo-machines (operating according to the Brayton or Renkin cycles) or thermoemission converters.

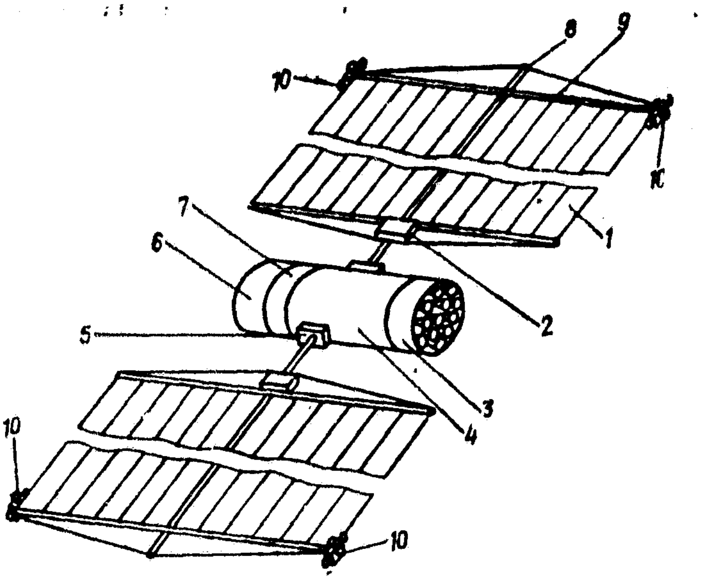


Figure 6. A construction-arrangement diagram of the acceleration stage with solar EREP: 1 - panel of the solar battery; 2 - unit for commutation and conversion of voltage; 3 - compartment with ERE; 4 - tank system for storing the working substance; 5 - drive for rotating the central block with slide contact; 6 - compartment for the payload; 7 - instrument compartment; 8 - mast; 9 - slide; 10 - ERE orientation.

Flights in the atmosphere with an electromagnetic engine. While efficiency of transport operations in near-Earth space (interorbital transport) in the future can be increased by transferring to higher energy rocket engines -- NRE and ERE, then improvements in the TSS on the "Earth-Orbit-AES" route will primarily use resources of the Earth's atmosphere. We have already mentioned plans for space gliders using the aerodynamic quality and air-propulsion engines for the acceleration section in the atmosphere. Another /39 approach to using the resources of the atmosphere, in the opinion of certain foreign scientists, is the creation of TSS based on an electromagnetic engine which generates an electromagnetic field in the ambient atmosphere for obtaining thrust.

The mechanism for creating thrust by the electromagnetic engine involves the effects causing strongly perturbed atoms and molecules. The disturbed atoms are formed due to selective absorption of photons (generated, for example, using flashbulbs) which communicate energy to the external electrons (the lifetime of perturbed atoms is from several milliseconds to 1 s). It is assumed that using intense radiation can create in the atmosphere surrounding the electromagnetic engine perturbation of molecules of nitrogen, vapors of water and oxygen.

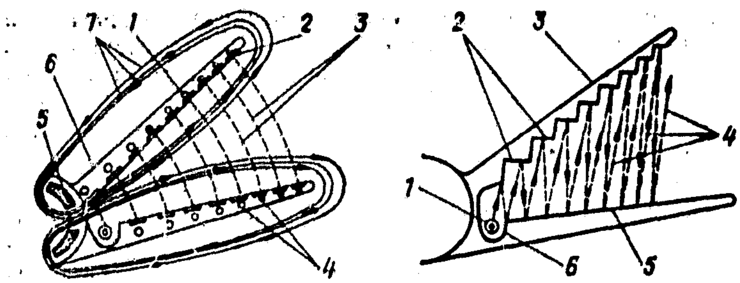
The perturbed molecules called excitrons are easily ionized. Acceleration of these molecules is provided by the effect of an alternating electromagnetic field with a certain frequency. Colliding with the remaining molecules of a gaseous medium, the perturbed molecules put them into motion. As a result, the entire mass of air found in the zone of effect of the oscillating electromagnetic field is accelerated which is accompanied by the occurrence of thrust in the space glider. With the voltage of the electric field 100 kW/m, magnetic induction 1 T, the working frequency of several tens of megahertz, a thrust occurs of 1000 N per 1 m^3 of air. One can judge the effectiveness of this type of TSS comparing the American design of space flight which has an electromagnetic engine has with the RTSC, the Space Shuttle. If, later, the ratio of expended power to thrust created equals 4500 W/N, then the prospective electromagnetic engine can provide this value at a level of 300 W/N (with conditions of an increment of velocity of the air surrounding the space flight about 300 m/s).

On the space flight it is proposed that one use a combination DU in which the lift force and thrust are provided due to the joint effect of aerodynamic forces, the forces of the electromagnetic field and the thrust of the LPRE. In principle it is possible to use the electromagnetic field and for braking the space wing with its return to Earth. The space wing with an electromagnetic engine is used for horizontal takeoff and landing; it looks like a biplane between whose /41 wings an electromagnetic field is generated. For obtaining electric energy on board there is a high-frequency magnetogas dynamic generator (MGD [Magnito-gazodinamicheskiy generator, Magnetic-gas-dynamic generator, MGD]). For perturbing molecules of air (without ionization) quartz flash lamps and a mirror are used.

According to the plan, in the MGD generator, combustion products from the LPRE are used operating on liquid hydrogen and liquid oxygen; a light ionizing additive (dope) in the form of a potassium compound is added to the combustion products. The plasma formed with the ionizing additive moves in the MGD channel at a speed of 3-4 km/s. The MGD-channel has two pairs of electrodes each of which is connected to the appropriate electrode on the wing of the spaceplane and provides action of the high-frequency electrical field in the ambient air. Moreover, for this purpose, part of the energy of the field created by windings of the MGD-channel magnet is intended for this purpose. Under the effect of the electric and magnetic fields, the air between the wings of the space wing moves in parallel to the flow of the plasma in the MGD-channel. The windings, the superconducting magnet and the walls of the MGD-channel are cooled by liquid hydrogen.

A diagram of the device for creating the electromagnetic field between the wings of the space wing and a diagram of the optical system on the wings are presented in Figure 7a, b. An overall view of the space wing with an electromagnetic engine is given in Figure 8. With a payload of 29.5 t this launch weight is 4 times less than that of the RTSC Space Shuttle and amounts to 570 t of which (in the suspended tanks) there is 400 t of fuel 45 t for electrodes and windings on the wings; 13.5 t for the MGD channel with the magnet.

In the future this type of TSS can be used for passengers or for cargo and passengers for serving large orbital stations and as assembly-mounting centers. However, along with the problems of developing the TSS with an electromagnetic engine, there also must be studied questions of safety for the crew on board and the effect of flights of the TSS in the ambient atmosphere from the point of view of possible ecological damage to the atmosphere.



a) b)

Figure 7. Diagrams of the layout (a) for forming an electromagnetic field between wings (1 - conductors, 2 - metal electrodes, 3 - lines of the electrical field, 4 - wing windings, 5 - winding of the magnet of the MGD-generator, 6 - insulation, 7 - power lines of the magnetic field) and an optical system (b) on the wings of the space aircraft (1 - flash lamps 2 - Fresnel reflector, 3 - wing, 4 - radiation field, 5 - flat mirror, 6 - reflector).

The TSS based on the electromagnetic mass-accelerators. In the preceding sections, we considered plans for the TSS in which all or a large part of the mass consumed and the energy for acceleration were stored on board the carrier. However, the scale of the transport /42 haulage in the era of industrialization of space (on the order of 1 million tons per year) forces us to look for another more effective principle for operation of the future TSS. With the tremendous power of the SSE which it is proposed to create in this period, this principle can be put into operation using external energy resources.

There is interest in this approach primarily for consideration of the second (nonproplusion) method of delivering cargo into space which was pointed out in 1933 by K.E. Tsiolkovskiy in his work entitled "Missiles acquiring cosmic speed on the ground and water." In a special electrical accelerator-cannon placed on Earth, the missile with a payload accelerated to a speed exceeding cosmic velocity and piercing the atmosphere puts an AES into orbit. K.E. Tsiolkovskiy also noted the advantages of this method as getting away from a "large reserves of explosive elements" that is from chemical fuel comprising a large part of the launch mass of a rocket using LPRE; the demand for electrical energy from the ground structure; reusing the accelerator device.

However, in this period, realization of this principle was not actually done in an engineering manner. In our time, the designs for such accelerators are affected by their own dimensions, the required power and will need in the future effective technical realization.

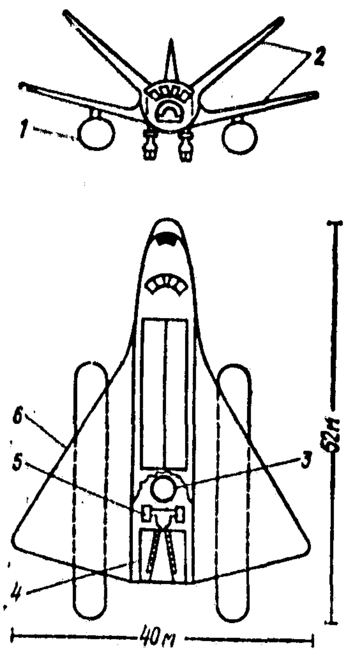


Figure 8. Overall view of a space aircraft with electromagnetic engine: 1 - suspended fuel tanks, 2 - wings, 3 - tank with ionizing additive, 4 - MGD-channel and magnet, 5 - LPRE cruise DU.

The most exemplary device for transporting large number of loads into space based on a nonproplusion method at the present time is considered to be the electromagnetic mass accelerator (EMU [Elektromagnitnyy mass-uskoritel', Electromagnetic mass-accelerator,EMA]) similar in layout to the magnetic engine. A container with payload equipped with superconducting solenoids is accelerated along a thick conducting fly-over due to the interaction of electromagnetic fields created by the container and the fly-over. The EMA must be equipped with a power source, energy-distribution and commutation equipment. On the accelerated container with superconducting windings which create an electromagnetic field with high intensity, there are cooling and control systems. For braking the container after separation from its accelerated mass, a special section of the fly-over is planned. The basic diagram for the EMA is shown in Figure 9.

Two variations of the EMA are known: accelerating windings which can be rectangular ("flat") in shape and positioned on both sides of the accelerated container and the accelerating windings which are ring-shaped and located coaxially to the container. In the first variation it is easier to accomplish a number of operational measures (axis to the container, the windings, etc. is simpler) and also the high-current control of the value and direction of velocity of the accelerated loads, which is an important factor in realization and use of all transport systems as a whole. In the second variation one achieves a higher efficiency in acceleration of the mass.

The ideal conditions for operation of the EMA are a deep vacuum and low temperatures, that is, space conditions. For the ground variation of the EMA it is necessary to take into consideration the loss of initial velocity of the capsule of the charge when passing through the atmosphere. Here the picture of the phenomena is the opposite of the traditional when the space vehicle goes into the atmosphere of a planet: the capsule, accelerating EMA, it passes at the maximum speed /44
the denses layers of the atmosphere and in the upper atmosphere moves with the least velocity so that the thermophysical and chemical processes occur more intensely up to altitudes of 30 km.

What are the characteristics of this type of device whose creation basically is possible in the future but which requires the solution of a number of complex scientific and technical problems?

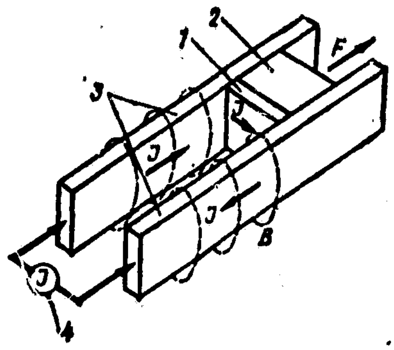


Figure 9. The main diagram of an electromagnetic mass-accelerator: 1 - mobile load bearing element with accelerated capsule (2), 3 - rigid current-conducting guides, 4 - current source.

A ground electromagnetic accelerator for acceleration of charges weighing 60 t up to a velocity of 10 km/s requires the power (acceleration of the charge is accomplished in 2 s) of about 3000 GW, that is, more than the established power of all USSR or USA power plants and therefore for the power supply to the accelerator one needs a gigantic energy accumulator. When this accumulator is switched on, for example, at the Krasnoyarskaya Hydroelectric Power Plant, it would be possible every half hour to send into space 1 charge which would place in 10 years, up to 11 million tons of load in AES orbit.

There is interest in the American design of the EMA for transportation from the Moon of cargo (for example, raw material in the form of useful minerals for space production of solar battery panels and design elements of the SSE). The system can provide, at a frequency of pulses 1 Hz, acceleration of individual useful loads weighing 20 kg up to a final velocity of 2.4 km/s and have a productivity of 600 thousand tons in a year. High precision in sighting is proposed (±1 m for a distance of 63 thousand km from the Moon) which makes conditions easier for receiving the modules of payload sent to the final destination (for example, into geostationary orbit).

The results of experimental studies here are very encouraging. A group of physicists at the Australian National University (in Canberra) along with other specialists have tested the "rail gun" several meters long -- basically the simplest of the electromagnetic accelerators of macroparticles. This device consists of two conducting current rails mounted in something similar to an artillery barrel. The pulses of electrical current sent along one rail return along the other. The first variation of the "rail gun" has a sliding connecting piece-conductor between the rails which is moved by the force of interaction of the magnetic field of the current flowing along the rail and the current of the cross piece.

During the experiments it was discovered that the metal fitting /45 can be replaced by an electric arc moving between the rails -- a plasma charge. The "charger" from nonconducting material or plastic can be pushed forward by this plasma. In the "rail plasma gun" a centimeter cube made of plastic was accelerated to a speed of 6 km/s. For high acceleration it is proposed that one position and sequentially switch on energy accumulators along the barrel of the gun because supplying them with current only at one end of the barrel leads to a considerable loss of electrical resistance with fairly long length of the rail.

In this way, the experiments confirm the possibility of creating an EMA for accelerating payload up to space velocities. The EMA, in combination with the SSE, as sources of energy can basically solve the problem of cargo flow in space and be ecologically pure TSS. A disadvantage of this method of going into orbit is too high acceleration loads which limit the type of payload, that is, basically, the EMA is designed for transporting raw material and semimanufactured goods.

A laser for servicing space transport. One more efficient method of mass launch of payload in space and with exemplary acceleration factor is the use of the TSS based on laser rocket engines (LRD [Lazernyy reaktivnyy dvigatel', Laser rocket engine, LRE]). Basically, the LRE operates on the principle of external intake of energy using the beam of well focused laser radiation for heating the working substance which is located on board the TSS. The flight of the TSS takes place on a trajectory programmed earlier and the necessary orientation of the transmitter and receiver of energy is achieved by a tracking system with feedback. Then the laser source of radiation can be placed both on the surface of the Earth and in space. The onboard LRE subsystem contains a concentrator for a laser beam and a light channel which provides intake of radiant energy in the heating zone.

The working substance, using the energy of laser radiation, is heated up to very high temperatures and is ejected outside through a supersonic nozzle with rates of emission (the specific pulse of the LRE can reach 1000-2000 s). As the working substance of the engine, /46 from an ecological and economical point of view, it is convenient to select water for example.

Studies of the technical aspects of the problem of designing LRE at the present time encompass the following basic approaches: study of the possibilities of two alternative procedures for operation of laser sources -- pulse and continuous; theoretical and experimental studies of different mechanisms of heating the working substance by laser radiation. Two systems of TSS are possible based on the LRE which differ in the method of intake of the laser beam into the chamber of the engine (Figure 10a, b).

In the first case, the laser beam is delivered through the engine nozzle, however, not losing its energy during passage through a stream of products of discharge and the nozzle (this system is called single-pass). In the second (two-pass system) the laser beam goes into the engine through a lateral aperture and is incident on a focusing mirror which deflects it and directs it to the aerodynamic window. The window lets the laser beam through into the absorption chamber but prevents release of gas from the high pressure chamber. Then, it must operate in conditions of constantly decreasing pressure of the ambient atmosphere (along the flight trajectory).

The working substance from the tank is fed to the engine chamber where it is heated using the energy of laser radiation. To increase the degree of absorption of laser radiation in the flow, a small quantity of gaseous additive must be introduced. The high temperature plasma forming in the heating zone is discharged through the nozzle where rocket thrust is created.

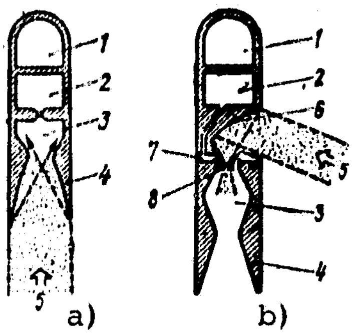


Figure 10. Diagrams of the TSS based on the LRE (a - single-pass, b - two-pass): 1 - payload; 2 - working substance; 3 - absorption chamber; 4 - nozzle; 5 - laser beam; 6 - focusing mirror; 7 - chamber with increased pressure; 8 - supersonic aerodynamic window.

For stationary (constant effect) LRE, the most flexible system according to working parameters and characteristics is the two-pass. For pulse LRE, the most exemplary is the single-pass system for intake of the laser beam. As foreign studies have shown, the efficiency of converting laser energy into thrust pulse of the LRE is slightly lower than the efficiency of the LRE with continuous action. However, the pulse LRE, thanks to the simplicity of its design (intake of the beam through the outlet channel) and the absence of possible problems related to limitations according to stability of the plasma, it has potential advantages over stationary LRE.

As the primary source of energy for the TSS based on the LRE, as for the EMA, the SSE is proposed. Here two methods of using this energy are possible: the direct transmission of energy developed by the SSE according to the laser beam on board the rocket and transmission of energy of the SEE on board the rocket through the accumulator. According to the first method, with standard power of the SSE on the order of 10 GW and actual efficiency of using the laser energy, one can put into orbit around Earth comparatively small payloads (up to 1-10 t).

When building a special accumulator for energy on Earth (based on superconducting elements, hydraulic storage batteries, etc.) the convertors and blocks of lasers with increased power in the massive payload carried can be significantly increased. For instance, using a TSS based on a LRE with the rate of discharge of the working substance (steam) 20 km/s, is possible to put a payload weighing 100 t with launch mass of the TSS about 200 t into orbit. Then, the working substance of the LRE, for its acceleration to a velocity of 20 km/s, requires increasing the power to 100 GW. The weight of the ground laser assembly transmitting energy on board the rocket (calculating specific mass of the assembly on the order of 1 kg per 1 kW of transmitted energy) amounts to 100-300 thousand t.

For conversion of payload from low near-Earth orbit to geostationary using the TSS based on the LRE, it is expedient to use laser assemblies located in space inasmuch as the ground assemblies, due to the need for compensation of loss when passing a laser beam through the atmosphere, requre very high supplied power.

It seems, realization of the plans listed above for providing mass launches of payload into space related to building on Earth of technically complex assemblies gigantic in scale requires large capital expenditure costing tens of billions of rubles would not be economically effective at first. But here we should mention what Academician V.P. Glushko concluded about this: "...They can object. To deliver, for example, a ton of useful minerals from a celestial body will be tremendously costly! But even the very first ton of coal delivered from a modern mine -- doesn't it cost that much today? It costs! But a thousand tons -- that's cheaper and a million -- we're down to the kopek..." /48

The TSS and Interplanetary Flights

The conquest of near-Earth space in the era of industrialization includes the creation of the SSE in geostationary orbit and the setting up of fuel and resource bases on the Moon, the creation of long-term OSS and assembly-operational centers, and finally, deployment in near-Earth and sublunar space a network of automatic relay satellites which practically convert the entire region between Earth and the Moon into a giant antenna system capable of moving spacecraft in the Solar System and even beyond its limits. All of this, naturally, will facilitate further development of study of the planets and interplanetary flights. However, the demands for the TSS for interplanetary flights differ considerably from the requirements for the TSS in near-Earth space.

If the main task of near-Earth space transporation in the future is realization of the large cargo flow with minimum cost and without disrupting the ecology of the environment, then for the interplanetary TSS, first of all, the question will be urgent as to the supply of the necessary energy for flight (from the point of view both of mass output of TSS for payload and for flight time). For comparison let us putting an AES into low geocentric orbit (taking into consideration all /49 losses) requires acceleration to a velocity of 9 km/s, flight to the Moon (at one end) up to a velocity of more than 12 km/s and for travel to Venus or Mars -- at least 40-50 km/s.

For interplanetary TSS it is necessary to look for more effective DU. Figure 11 shows a specific pulse (depending on the total "reserve of velocity"), necessary for flight with a certain weight of payload for prescribed distances. One can see that for flights to Venus, Mars, Jupiter and Mercury with relative weight of the payload 0.5, the required value of the specific pulse must amount to from 4000 to 9000 s. Then the engines must provide adequate thrust-weight ratio in order to decrease the time for interplanetary flights to exemplary values. This requirement can be met by pulse (pulsing) NRE and next we will look further at TSS based on such engines.

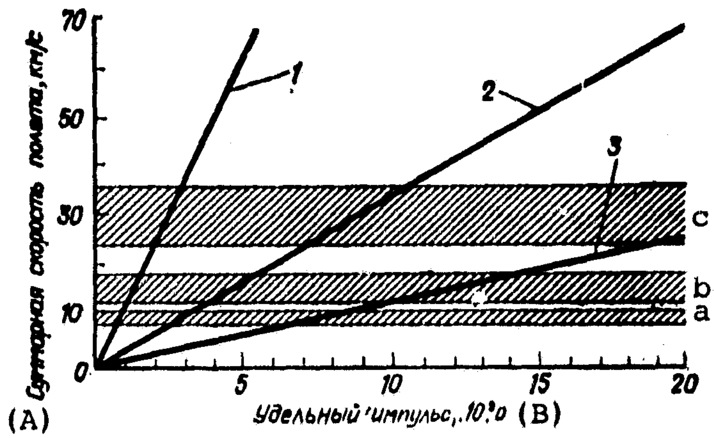


Figure 11. The connection between the required specific pulse and the total flight velocity for different values of relative weight of payload (a - putting an AES into orbit; b - going to Venus or Mars; c - to Mercury or Jupiter): 1 - 0.25-0.35; 2 - 0.5-0.6; 3 - 0.65-0.75.

Key: (A) Total flight velocity, km/s;
(B) Specific pulse, 10^3.0

Transport vehicles based on the pulse NRE. These unusual engines are devices in which the thrust is created by using energy from explosions of a large quantity of nuclear charges with comparatively low power located on board the TSS. These charges are sequentially ejected /50
from the transport craft and explode behind it at a certain distance on the order of a few tens or hundreds of meters. Then the explosion of part of the gaseous fragments for separation in the form of plasma with high density and velocity hits the base of the vehicle -- a special buffer slab platform equipped with damping devices. Movement of the fragments is transferred to the buffer platform and it moves forward with great acceleration.

The damping devices in manned TSS can decrease the acceleration and provide exemplary acceleration low in the area of the crew compartment. After a cycle of compression, the shock absorbers turn the jolted platform into its initial position after which it is ready again to take on the next pulse. The total increment of velocity of such a vehicle depends on the reserve of nuclear charges on board it (Figure 12).

Thrust can be created not only by the direct effect of striking particles (products of the explosion) but due to transmission of their kinetic energy of the working substance discharged from the NRE. As the working substance one can use, for example, a solid substance which is easily converted into gas which strikes the buffer slab or liquid hydrogen specially emitted from the tank. Due to the small productiv- /51
ity of the single effect from the explosion (about 1 ms) increased

temperatures will be permissible in the working zone (up to $8\cdot10^4$-10^6 K). In order to increase the specific thrust of pulsing NRE, it is expedient to use charges with a special shape (in order to impart directionality to the explosion) and also to include charges in special shells (during whose instantaneous evaporation a shock wave was created). Theoretical estimates give a specific pulse of pulsing NRE using ordinary nuclear charges (with a fissonable substance) from 2500 to 5000 s.

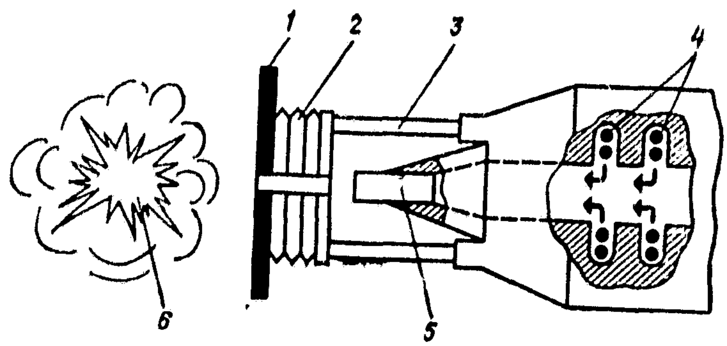


Figure 12. The operating principle of the pulse NRE: 1 - buffer slab; 2 - jolting platform, elastic damper; 3 - piston shock absorber; 4 - reserves of nuclear charges; 5 - mechanism for ejecting the charges; 6 - explosion of the nuclear charge.

In spite of the unusual principle of operation, the pulse NRE is looked at as a completely possible thrust device. An evaluation of the possibilities of such an engine was presented in the USA for development in the 1960's of the Orion project which included the creation of a space rocket based on a pulse NRE which uses energy of explosions of plutonium bombs. According to calculation, such a rocker with a launch mass of 3600 t provided delivery onto the surface of the Moon of a payload weighing 680 t for which one would need to explode 800 bombs and use up a total of about 800 t of the working body (calculated for an easily evaporating low-molecular substance applied to the buffer slab). The possibility of accelerating the aircraft directly by a series of sequential explosions was confirmed experimentally on flying models put into motion by the energy of explosions of charges of TNT.

At the present time, the prospective pulse NRE involves the use of thermonuclear charges which are more effective than the ordinary nuclear charges. In distinction from the latter, in thermonuclear charges the minimum mass, and consequently, power, is not limited by the criticality factor. Moreover, in thermonuclear explosions of pulse NRE it is possible to use a deuterium-tritium fuel; the complexity of using it in ordinary NRE was noticeably higher. As the detonator for the explosion it is proposed that a laser beam be used or a powerful electronic beam passing through a self-focusing magnetic field. The specific pulse of the pulse NRE with thermonuclear charges, according to estimates, amounts to from 5000 to 10,000 s.

The basic requirements for interplanetary TSS based on such engines are the single-stage character, reuseability, the possibility of operative flights within the limits of the Solar System (including the atmosphere of planets), relative mass of payload at least 20%, the possibility of using several types of fuel as the working substance which simplifies fueling in conditions of landing on other planets. For instance, for pulse NRE, besides hydrogen as the working substance, one can use water giving a fairly high specific pulse. Water is convenient for storage and abundant on Earth, Mars, the satellites of Jupiter and other bodies of the Solar System. It can be included in the shell of a nuclear charge or directly put into the gap between the protective shield and the impact wave from the explosion. In the latter case, the working substance would partially absorb the energy and simultaneously cool the shield and therefore introducing large or small quantities of working substance into the explosion zone would regulate the thrust of the engine. /52

A disadvantage of the TSS based on pulse NRE is contamination of the space with radioactive particles formed during the nuclear explosion. This is why they are proposed for flights far from Earth and revitalized "space channels." For takeoff of the TSS from the surface of Earth in order to avoid contamination of the atmosphere, in a number of designs for such systems, it is proposed that one have a combined DU with ramjet engines.

Interplanetary TSS based on ramjet TNRE. The principle of operation of any ramjet engine is based on capture of the external medium, intake of energy to it and ejection of the propulsion mass through the accelerating flow of the nozzle. The idea of a ramjet TNRE includes the use for thermonuclear synthesis of hydrogen present in the interplanetary medium and in transmitting the energy generated to a flow of particles captured by the mass intake from the external medium for acceleration. In this way, the duration and distance of flight of the TSS based on TNRE is not related to the reserves on board of mass and energy (one or the other comes from the external environment) and depends only on the safe life of the onboard system. Even the initial /53 reserves of launch thermonuclear fuel (deuterium and tritium) in the process of flight can be obtained from the interplanetary medium where these isotopes of hydrogen also occur in a certain quantity.

Capture of the external atmosphere is accomplished by means of ionization of particles of the incoming flow with subsequent focusing of it using a magnetic field especially shaped in front of the transport craft. For this, along the perimeter of the mass collector with fairly impressive dimensions (diameter about 20 m and length about 25 m) are placed threads of a superconducting winding with a current cooled by liquid helium. From the leading part of the central body of the mass collector the flow from the opposite direction is directed by the beams -- a bundle of accelerated electrons or any type of radiation (gamma-, X-ray or ultraviolet).

The incoming flow of hydrogen is ionized by radiation and if a bundle of electrons is used, then it is focused ahead of time confining it close to the axis of the beam using the force of electrostatic interactions. The ionized particles of the flux (basically protons and electrons) are captured by the magnetic field of the transport vehicle and moving along the power lines of the magnetic field are confined to the intake in the mass collector. Focusing using the magnetic field essentially increases the effective area of the mass collector. According to analysis, the effective diameter of the electromagnetic mass collector can in the future reach several hundreds up to thousands of kilometers.

With the density of the interplanetary medium on the order of 10^{-17} kg/m^3 and flight velocity 100 km/s, in such a mass collector for 1 s about 1 kg of hydrogen enters and if 75% of the incoming hydrogen reacts in the thermonuclear device, then the generation of energy amounts to $5 \cdot 10^{11}$ kJ/s. Taking into consideration possible losses during magnetic focusing (due to different types of instability) and incomplete use of generated thermonuclear energy for acceleration of the jet stream, the actual thrust of such TNRE will be about 1000 kN and provide for the TSS the possibility of acceleration for a limited time from the orbital near-Earth velocities to a velocity on the order of 1000 km/s. Then manned flights to Mars and Venus can be completed in 2-3 months and to distant planets of the Solar System -- in a few years.

The external appearance of the TSS based on a ramjet TNRE is unusual in flight. In front of the transport spacecraft, at a large distance, bright violet ionizing beams are propagated. On the periphery of this beam flashes and illumination occur related to the decay of the micrometeorites and space dust encountered on certain molecules and atoms and with their ionization along with other particles of the interplanetary medium under the effect of a powerful flow of accelerated ions. Collision with large meteorites can be avoided by early detection and by making avoidance maneuvers. Maneuvering and braking the spacecraft will be accomplished by changing the operating regime of the reactor and controlling the "magnetic depression" of the mass collector which, for certain conditions, can act as the brake. /54

A photon rocket. A ramjet TNRE which we discussed above, in principle, does not have limitations in flight range and can be considered for accomplishing interstellar flights. However, according to present-day data, the density of interstellar hydrogen is considerably less than interplanetary (10^{-21} instead of 10^{-17} kg/m^3). Therefore, the thrust of such an engine in an interstellar medium does not exceed a few Newtons which is not suitable for manned TSS due to the great length of the flight. The graduated acceleration of the TSS also can not be done for such a high level of thrust inasmuch as, as one increases velocity of the incoming flux, a large part of energy ejected on board the TSS will be expended in increasing the intensity of the magnetic field of the mass collector.

Increasing the power of the engine in this case, obviously, is possible due to transition from a thermonuclear reaction of synthesis of hydrogen to reaction of annihilation of hydrogen and antihydrogen during which approximately 1000 times more energy is generated than during synthesis of hydrogen. If one directs the radiation formed during annihilation toward one side with a beam similar to a stream from a jet engine nozzle, then we obtain the so-called photon engine with a velocity of discharge of the working substance close to the speed of light.

The portion of antimatter in the environment is extremely small and therefore the antimatter must be stored on board the TSS. However, the problems of obtaining it and storing it are still far from solved and can't yet be put on the day's agenda. There are still no concepts of methods for delivering antimatter into the reaction zone. The question of effective conversion of energy of photons to kinetic energy of a jet stream is extremely complex.

Focusing and reflecting photons using an ordinary reflector with /55 rigid walls is unthinkable inasmuch as the photons of the annihilated substance in the initial form are high-frequency gamma radiation with a high penetrating capability for which even ideally polished screens are similar to a lattice. The most promising for the modern concept is calculating a hypothesis on the use (for focusing quanta) of a disk-shaped electron cloud held by this same magnetic field which provides operation of the electromagnetic mass collector.

The possibility of creating a TSS based on a photon engine is very far in the future. This approach to the development of thrust systems is closely related to successes of fundamental and applied studies on thermonuclear synthesis, high temperature superconductivity, the theory of the field of elementary particles, methods of obtaining and storing antimatter, etc. Today the photon engine is theoretically the highest energy engine of all proposals for TSS.

<u>Possibilities of flight to the stars</u>. In a 26-year period of development of practical cosmonautics, man has traveled a distance of 380,000 km from Earth (the flight to the Moon), automatic spacecraft have been to Mars and Venus, from their flight trajectories they have studied Mercury, Jupiter and Saturn. On April 25, 1983, the Pioneer-10 intersected the orbit of Pluto at a distance of 4.5 billion kilometers from Earth and in June 1983 an orbit of Neptune was completed.

With such grandiose and complex missions facing mankind with the accomplishment of flights to stars, in comparison with successes already achieved in studying cosmic space near the Sun, it is possible to judge only graphically the scale of interstellar distances facing us.

Beams of light from the small red star Proxima Centaura in the stellar system of Alpha Centaura takes 4.27 years to come to Earth and the distance to it is 270,000 times greater than the distance from Earth to the Sun. If, for a graphic presentation we decrease the Solar /56 System in such a way that its entirety is the size of a post card, that is, 12 cm in diameter, our Galaxy correspondingly is decreased to a diameter less than 9000 km, that is, it can be put approximately in the territory of the Soviet Union and the star closest to it, Proxima Centaura, will be at a distance of 500 m from the post card. In order to leave the Solar System, the TSS must have a velocity when leaving the Earth of about 16.7 km/c. But even during flight with a velocity of 20 km/s, for reaching the nearest star, one needs 66,000 years.

The absurdity of such a trip is obvious. For decreasing time periods, it is necessary to increase flight speed. Inasmuch as we are working with distances which a light beam takes years to cover, the TSS in interstellar flights must develop speeds close to the speed of light. If for the duration of a flight we take the lifetime of one or two human generations (about 30-60 years), then for flight to the star Proxima Centaura, one needs values of acceleration and velocity which are shown in Table 2 (then one allows a continuous acceleration for half the route with subsequent braking).

Table 2. Characteristics of Flight of TSS to the star Proxima Centaura

Ускорение (a)	0,2 м/с² (b)	0,4 м/с² (c)	1,0 м/с² (d)
1 Наибольшая достигаемая скорость, км/с	$0{,}9 \cdot 10^5$	$1{,}26 \cdot 10^5$	$2 \cdot 10^5$
2 Время путешествия для экипажа (в оба конца), годы	56,8	40,0	25,3

Key: (a) Acceleration; (b) 0.2 m/s^2; (c) 0.4 m/s^2; (d) 1.0 m/s^2; 1 - Largest allowable velocity km/s; 2 - time of travel for the crew (at both ends), years.

Now if we evaluate the necessary energy consumption for realization of manned flights on the basis of well-known and promising thrust systems, then in recalculating the fuel required for flight with an interstellar spacecraft weighing 1000 t, the lowest stress for a manned flight program (with acceleration 0.2 m/s^2), they would amount to $37 \cdot 10^{11}$ t for a chemical engine, $38 \cdot 10^4$ t for a nuclear engine, $48 \cdot 10^3$ to for a thermonuclear engine, $2 \cdot 10^2$ for an annihilation engine. Actually, only the latter variation can be exemplary /57 for the weight ratio of the TSS for the necessary weight of fuel but it has not actually been accomplished. In order to present how much energy is required for this flight one should note that in the last 20 centuries mankind has used up for all of his needs an energy only as large as could be obtained during annihilation of 100 t of antimatter, that is, half of the reserves of fuel necessary for manned flight to Proxima Centaura.

And all of this human pursuit "beyond light and space" is continuing. The research and analysis development in this direction is being done abroad. The American project of a two-stage interstellar TSS based on the pulse TNRE is well-known. For launch weights of the first stage, on the order of 48,000 t, and the second stage, about 5000 t, acceleration of the spacecraft weighing 500 t will be accomplished up to a velocity equal to 0.122 times the speed of light.

There are proposals for using in the TSS for interstellar flights, laser ramjet engines in which the energy for heating an accelerating plasma is conducted to the ship with near-solar intermediate orbits according to a laser beam created by an installation obtaining energy from the Sun. It is proposed that a laser DU be used for sections of acceleration to the speed of light with simultaneous collection of interstellar deuterium for operating the pulsing TNRE. An estimate of the mass of such a TSS in very approximate. The value of the launch mass on the order of 8000 t and the value of the mass of interstellar substance accumulated during flight as 12 thousand t are the first rough estimates. Then the necessary power of the laser beam must be equal to $3.5 \cdot 10^8$ MW. In this case, the dimensions of solar batteries in near-Earth orbit force power supply for the laser (without calculation of loss) exceeds 500X500 km and the diameter of input of the ramjet engine installation in the TSS amounts to about 650 km.

In this way, even with very clever technical predictions and solutions, the manned flights to stars is still not a problem which can be solved in practice. But really the problems related to the first flight of man in space, landing on the Moon or launching automatic spacecraft to distance planets seemed in the beginning to be just as complex and grandiose did they not?

The conquest of space continues. Space transportation faces new tasks but at the same time new possibilities are opening up. Deployment in the future of SSE makes it possible to transfer to a qualitatively new type of TSS using external energy sources (EMA based on laser engines) which provide realization of large cargo flows in near-Earth space. /58

The development of nuclear power in the future will lead to the creation of TSS based on TNRE (pulsing, ramjet) which opens up broad possibilities for manned flight within the limits of the entire Solar System.

Improved TSS based on traditional DU will be used. Transportation systems based on LPRE using external resources (the atmosphere) can effectively solve new problems of manned flights and the launch of applied AES in near-Earth space and nuclear and electrorocket TSS will accomplish interorbital transportation of cargo and unmanned flights in outer space. The decades are passing. And from the position of new achievements of science and technology the problems of flight to stars can be very important for predicting the development of TSS. Improvement and transportation systems will continue along with the conquest of space.

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