Concatenated JPRS Reports, 1991

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Classification: UNCLASSIFIED **Status:** [STAT]
Report Type: JPRS Report **Report Date:**
Report Number: JPRS-USP-91-005 **UDC Number:**

Headline: Annotation

Source Line: 00000000

FULL TEXT OF ARTICLE:
1. What's been done so far and what may lie ahead- something of a summary of the development of the space program, and an attempt at predicting how it will develop-are what is contained in this brochure, written by one of the planet's first cosmonauts.

2. The brochure is intended for a broad circle of readers.

3. Thirty years have gone by since the first man flew into space, and 33 years since the launch of the first artificial Earth satellite. One naturally wants to ask oneself, Just what have we succeeded in doing? What new things have we learned? What have we gained that is of practical value?

4. What's Been Done So Far?

5. In terms of manned flight, we can list the following achievements:

6. We have found out that man can live and work in orbit for a year (and probably longer).

7. We have performed six lunar missions.

8. Man can work in open space (in a space suit), but his mobility and his capabilities there are extremely limited.

9. Man can do research in space, altering its programs and aims in the course of a mission. His capabilities, however, are largely determined by the equipment on board, and he cannot compete with automatic devices in terms of accuracy of execution of precision operations.

10. Manned spaceflight has not given us any fundamentally new information (other than data on man himself in weightlessness and data on the operation of the flight systems themselves in space), and we are powered by the hope for now that we will be able to do something of substance in the future.

11. We still haven't found an ''ecological niche'' in science,

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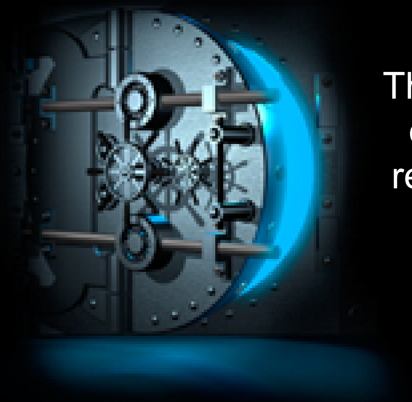

technology, or economics for a man working in orbit (the practical work that has been done so far-making observations and turning cameras, instruments for observing outer space, and experimental equipment on and off- could have been done, theoretically, with automatic devices that, for the moment, can compete with man in everything but the repair and replacement of individual instruments and pieces of equipment; but the slot of ''repairman'' is hardly a secure, long-lasting niche).

12. In terms of applied, in-orbit activity that is beneficial to the people on Earth, the use of unmanned spacecraft has produced much better results. In that regard, we can name the following important achievements:

13. a marked expansion of the capabilities of telephone, telex, and computer communications through the use of communications satellites

14. intercontinental television communications

15. global weather monitoring with weather satellites, and dramatically better accuracy in weather forecasting and in warning of approaching natural disasters

16. improved maritime and airways navigation through the use of satellite-based navigation systems

17. greater reliability in the receipt of distress signals and in the identification of the area from which a signal is coming as a result of the use of satellite systems like Cospas-Sarsat

18. the capability of global and local ecological monitoring of land areas and sea surfaces and of the study of the Earth's natural resources with satellites

19. observation of land areas and sea surfaces with reconnaissance satellites not only for purposes of military reconnaissance, but also for monitoring adherence to international arms-limitation agreements.

20. Unmanned spacecraft have been used to obtain important new information in the field of scientific research. Such information includes the following:

21. discovery of the Earth's radiation belts

22. research findings associated with the Earth's ionosphere and magnetosphere

23. discovery of ''solar wind''

24. confirmation of the absence of life on the Moon and on Venus

25. data on the atmospheres and surfaces of Venus and Mars (composition, density and pressure variation with altitude, relief)

26. large-scale maps and photographs of the surfaces of the Moon, Mars, and distant planets of the solar system and their moons

27. detection in the celestial sphere and mapping of sources emitting in the ultraviolet, X-ray, and gamma ranges of electromagnetic radiation

28. detection in the celestial sphere of sources of X-ray and gamma bursts

29. confirmation of the existence of neutron stars and ''black holes'' in the Universe

30. discovery of heretofore unknown processes occurring in the Universe (matter transfer between close binary star systems, accretion of matter on the surface of neutron stars, accretion of matter on ''black holes'').

31. In terms of the creation of technical systems for space hardware, we have, of course, achieved great success. But we shouldn't flatter ourselves too much: after all, the space hardware has been working, so to speak, for itself.

32. Here we could note the following important efforts. First, various systems for putting spacecraft into orbit have been created:

33. expendable rockets, among which we could name, for example, the Soviet rockets of the R7 family (capable of putting a payload of about 7 tons into orbit), the Proton family (approx. 20-ton payload), Zenit (approx. 13-ton payload), and Energiya (payload on the order of 100 tons); the American rockets of the Atlas family (with Atlas-Agena capable of putting payload of about 3.4 tons into orbit), the Titan family (the Titan 3C can put about 12 tons into orbit), and the Saturn 5 (capable of lifting 137 tons); and the French rockets of the Ariane family (the payload mass of the Ariane 5 is expected to be about 20 tons)

34. ''reusable'' transport systems: the American Shuttle system (with a payload mass of about 30 tons) and the Soviet Buran system (the payload mass is expected to be up to 30 tons).

35. Second, systems for manned flight and manned operations in space

have been created-manned spacecraft and orbital stations: the single-seat Vostok, capable of up to 10 days of flight; the single-seat Mercury (up to 24 hours of flight); the three-seat Vostok (up to three days of flight); the two-seat Gemini (up to 15 days of flight); the three-seat Soyuz (up to 20 days of independent flight and six months of flight as past of an orbital station); the two-seat lunar mission craft (up to 30 days of independent flight); the orbital Skylab stations; the Salyut-series stations; and the multimodule Mir station.

36. Next, unmanned space vehicles have been created for scientific research. The most outstanding results have been produced with the Explorer 1 (discovery of the Earth's radiation belts); the Luner Orbiter (mapping of the Moon's surface from a satellite orbit); Luna-16 (delivery of soil from the lunar surface to Earth); Luna-17 (the self-propelled vehicle controlled by an Earth-based operator); Venera-4 (first data on the parameters of the Venutian atmosphere); Mariner 9 (studies and mapping of the surface of Mars from a satellite orbit); Viking 1 (studies of the surface of Mars and a search for signs of life in the vicinity of the landing site); Voyager (studies of the distant planets of the solar system); Uhuru, Ariel, SAS-3, Vela, Copernicus, ANS-1, COS-8. HEAO, and IUE (basic astrophysical research in the X-ray and UV ranges).

37. And last of all, the unmanned space vehicles for applied operations in Earth satellite orbit. Among them one cannot fail to include the communications satellites (Intelsat, Comstar, Sincom, Ekran, etc.), satellites for studying the Earth's natural resources (Landsat, Seasat), navigation satellites (like Navsat), weather satellites, reconnaissance satellites, and satellites for relaying distress signals and for determining their coordinates.

38. The Experience We've Garnered

39. The experience we've garnered is quite varied. By and large, it relates to the rather well-known tasks associated with the development, manufacture, testing, and operation of rocket and space hardware.

40. For example, problems related to safety surrounding the launch of rocket systems. Those problems mainly involve the large quantities of oxidizer and propellant that are loaded into the rocket. Toxic components, as they are used in such a rocket, make things very complicated at the launch site. There is always the danger of a breach in the integrity of the fueling system or the rocket itself, which would be fraught with catastrophic consequences. When components such as nitric acid, nitrogen tetroxide, hydrazine, or dimethylhydrazine are used, the danger to the personnel who are

servicing the rocket is great, and stringent safety measures must be observed. Even if the rocket and its launch systems are designed so that there are no personnel present at the launch pad after fueling operations begin and before liftoff and even if all processes that involve mating the fueling systems, checking their seals, and the fueling itself are automated, there is still always the danger that something will go wrong, and specialists will have to go near the rocket during the fueling process or after it is completed. Gas masks, special protective clothing, and highly sensitive gear for monitoring the gas composition of the air are necessary gear for personnel at the launch sites for such rockets.

41. Even for today's rockets, normal flight involves certain complexities. First stages fall back to Earth, which means that drop regions that may be dozens of square kilometers in area must be removed from public use. The situation with rockets that use toxic components is made more complex by the fact that, among other things, first stages can break up when they hit the surface, and over time the residues of the toxic components can build up in the drop regions and make their way into the ground water.

42. In a word, rocket systems in the future should be based on the use of ecologically clean components such as kerosene/oxygen or hydrogen/oxygen.

43. Moreover, we need to consider the interaction that takes place between the burning of rocket fuel and the atmosphere, particularly the ozone layer. Standard liquid-propellant rockets apparently present no danger; but in the use of solid-propellant rockets, there is the danger that the combustion products will interact with ozone, since they can be very effective catalysts of its decomposition.

44. The entirely real danger of an accident during the powered phase of flight-and, accordingly, the danger of the rocket fragments falling to the Earth along the flight path-imposes strict requirements on the choice of launch site and ascent trajectory, so that the rocket will not pass over densely populated regions.

45. The danger of an accident with catastrophic consequences always exists during the flight of a rocket. It stems from the very high concentration of energy (hundreds of tons of fuel) in the rocket and the power in the rocket engines, from the strain on the structure, and from the small number of flights of that particular model of rocket (by comparison with, say, automobiles or airplanes). The danger presented by rockets is clearly illustrated by the power inherent in the rocket engines. For example, the engines of an R7 rocket in the first stage have on the order of 10 million horsepower, and the engines of the Shuttle rocket system, on the order of 70

million horsepower. The danger is always clear in the mind of the developers. Even the first American spacecraft-Mercury, Gemini, and Apollo-had good rescue systems that effected the separation and swift removal of the spacecraft from a launch vehicle breaking up as a result of a failure. A fairly good emergency system for rescuing the cosmonauts during a launch-vehicle failure was created for the Soyuz craft. Twice it saved the lives of cosmonauts-once during a third-stage failure, and once during an emergency at the launch pad.

46. Design difficulties do not justify the absence of a full-fledged rescue system in the event of launch-vehicle failure. Such a system is conspicuously absent in the Shuttle system and represents its chief shortcoming.

47. After the separation of the spacecraft or unmanned space vehicle from the launch vehicle, the upper stage usually remains in orbit, gradually slowing and then entering the dense layers of the atmosphere, where it burns up for the most part, and its fragments fall to Earth. If the altitude of the injection orbit is low (less than 200 km, for example), that process takes several days. But if the altitude is high, the upper stage may remain in orbit months or years.

48. It must be said that that eventually becomes a problem. At this moment, the quantity of upper stages that remain in near-Earth orbit-along with space vehicles that are no longer in operation, connective structural elements, and fragments produced by break-ups or accidents involving space vehicles-is such that the danger of a collision with them has become comparable to the danger of a collision between meteors and long-duration space vehicles, spacecraft, or orbital stations. That is why an urgency attaches to the problem of using injection profiles in which the upper stage of the rocket does not remain in orbit. Just such a profile is used in the Shuttle system: after the second stage shuts down, the fuel tank separates from the craft and returns to the atmosphere, and the intact remains fall into a specific region of the ocean. That is how launches should be done in the future. A similar requirement should naturally be imposed on the design of space vehicles, so that just before they shut down, they are ''pushed'' from orbit, and after their stay and maneuvers, no structural parts or fragments whatsoever remain in orbit and there is no gradual build-up of dangerous (deadly!) garbage in near-Earth orbits.

49. Based on all the above, the following recommendations need to be made for orbital injection systems:

50. Use of rockets that operate on toxic components is extremely undesirable, at least for putting manned craft into orbit.

51. Full-fledged emergency rescue systems need to be installed on rocket systems used for putting cosmonauts into orbit.

52. After injection, the upper stage of the launch vehicle should not be kept in orbit long.

53. We need to verify (if only with theoretical calculation) the absence of the danger of any harmful effect produced by the rocket fuel combustion products on the ozone layer of the atmosphere.

54. We must not forget what we learned in the lunar program.

55. On 20 July 1969, we gazed at the Moon with feelings that were unusual, new for us all. On that day, humans- Armstrong and Aldrin-were walking on its surface, at a fantastic distance of 400,000 km away! That event was perceived as (in the words of Armstrong) a ''giant leap for mankind.'' An impressive range of operations and an impressive result. Complete success.

56. The euphoria felt at the time by the project's developers and probably by most of the American people was understandable and quite natural: ''We're on the Moon! That's us on the Moon, and not those Russians who are eternally behind in everything.... Our natural position in space research has been restored (and our prestige, too).... What we had perceived at one time as a sort of abstraction, a sort of pretty, unalterable detail of the sky, has turned out to be a real world after all, one on which you can walk, and ride-one you can touch. This is a historical achievement, and it's ours!''

57. Emotionally, that historical show that was put on for the whole world meant, of course, a great deal: you could feel that you were a participant on that unusual journey and adventure, you could feel the Moon under your own feet.

58. We could congratulate the Americans and the all the rest of us again on that magnificent achievement. And why not. But something raises some doubt, something is not quite right.

59. The landing of N. Armstrong and E. Aldrin on the Moon was the beginning of the lunar project. Between 1969 and 1972, the Americans delivered six missions to the Moon. What can be considered a plus about the lunar program?

60. Twelve people spent time on the surface of our satellite. In all, they covered nearly 100 km of it on foot or by vehicle, and they brought back nearly 400 kg of lunar rock. But in and of themselves (apart from the advertizing/souvenir aspect of the matter), those

rocks provided no fundamentally new or valuable information to anyone (except, perhaps, geologists and geochemists).

61. Maybe some other kind of information of substance was produced? It would seem not.

62. Positive emotions and prestige for the United States- yes, of course. But ''$25 billion for prestige'' (that's how much those shows cost) sounds a little absurd. And sad. After all, all the space programs that could have been performed for that immense amount of money must be written off as lost.

63. An endeavor to restore the prestige of the United States as the leader in technical progress was the main reason for undertaking the lunar program. The fact is that our country was, for a time, ahead in the matter of penetrating the depths of space: in 1957, we launched the first satellite; in 1961, we sent the first man into space.

64. How did such a thing come about? How did we get ahead, despite the immense technical potential of the United States? The fact is that launch vehicles, space vehicles, and spacecraft are manufactured in small numbers (especially back then-when space operations were beginning). It was virtually individual production, i.e., it was, in a sense, homemade. Under those conditions, leadership was determined by ''brainpower'' and efficiency. It would be absurd to say that our brains were better than theirs; but we can, in fact, say that ours were no worse than theirs. And space bureaucrats and careerists had not yet managed to firmly attach themselves. So the initial conditions were roughly the same. And of course, we didn't underestimate the American engineers (although they underestimated our engineers, and, in my opinion, many Americans still do); underestimating a rival is a serious mistake. And to get some recognition in something like making it into space was something we wanted. Not expecting any directive orders from the leadership, we set our own goals. We worked diligently, without any fascile optimism. After our first successes, many Americans probably felt some discomfort, and their pride may have even been wounded. It's hard to say right now who it was that proposed landing on the Moon as a way of restoring prestige. In the final analysis, it doesn't matter. But all the same, the goal clearly wasn't worth the money spent. That's not to belittle the magnificently executed engineering work of the Americans. The point is how little the experience gained as a result of tackling and performing the lunar project was used. Over the course of the project, as a result of an immense amount of well-coordinated work, the Americans created not only the Apollo spacecraft and the Saturn 5 rocket, but also a gigantic production and experimental base: hold-down stands for testing rocket engines, equipment for preparing rockets and spacecraft for launch, etc. And

after 1972, almost none of it was used. It was abandoned, discontinued: there was nowhere to continue to-the lunar program had turned out to be a deadend. It was an example of a clumsily chosen-more precisely, an incorrectly chosen- goal.

65. A goal involving the spending of $25 billion or even $100 billion on a grandiose space undertaking (if the country is rich and the taxpayers agree to it) is not absurd in and of itself. But one must think clearly when making the decisions and choosing the goals.

66. Roughly the same must be said about the American Shuttle program and especially about the imitative Soviet Buran program. The idea of the Shuttles consisted in lowering transportation expenditures between Earth and orbit. The goal was a correct one. But the profile and design solutions that were adopted were clearly awkward, and the plan was not fulfilled: the delivery of cargoes to orbit with the Shuttle (never mind our own natural disaster, Buran) turned out to be, to put it lightly, considerably more expensive than delivery on the expendable launch vehicles that had been used earlier.

67. Forthcoming Tasks in Space

68. At present, there is still no one common opinion on the most important directions to be taken in the development of human activity in space. Slogans like ''The Mars Mission-An Inspiring Goal,'' ''Let's Make an Impressive Leap Forward in the Exploration of Space,'' ''Let's Open the Future...,'' and ''Let's Explore the Solar System'' often replace well-thought-out, logical proposals in the selection of paths to be taken in moving farther forward. The most varied of programs are being proposed.

69. For example, a program linked with the American astronaut Sally Ride proposes as the principal goals for the next 50 years the creation of bases on the Moon, asteroids, and planets; systems for traveling about the solar system; and space settlements.

70. Soviet scientists working in basic sciences feel that in the next decade we should concentrate our efforts on a study of near-Earth space; research on the Earth's magnetosphere; research on solar-terrestrial relationships, the Sun, the solar corona, and Mars; and astrophysical studies with unmanned space vehicles.

71. There are proposals that are more pragmatic. They involve a program for exploring near-Earth space and are aimed at developing satellite systems of communications and television, creating satellite systems for environmental monitoring and the study of the Earth's natural resources, developing systems of weather satellites, and creating in-orbit production that is economical and efficient.

72. So opinions are quite diverse.

73. It's probably wrong to pit pragmatic endeavors against people's natural wish to expand the sphere of their activity and to learn more about the Universe and our place in it.

74. In choosing the path we will take from here, it would be more sensible to strive both to satisfy mankind's most intrinsic needs and to study the world around us.

75. Among the most urgent problems facing mankind today are the ecology and the depletion of natural resources, political instability in the world, the separation of nations and the lack of trust between them, and the growing overpopulation of the Earth.

76. In terms of studying the Universe, the following tasks, in my opinion, could be considered the most interesting: solar system studies; studies of stars, galaxies, and celestial objects at the edge of the Universe with astrophysical instruments; and studies of the possibilities of flights to the stars.

77. In the context of such an approach, the following basic directions for space operations could be proposed:

78. 1. Activity that satisfies the intrinsic needs of mankind. Such activity would involve work of an applied nature that could provide specific benefits to people and would be, if possible, economically profitable.

79. Such activity can be divided into three groups of operations.

80. Group A consists of already established, almost traditional operations such as environmental monitoring of land, sea, and ocean surfaces; studies of natural resources with space vehicles; and satellite services involving weather forecasting, navigation, detection of distress signals, and communications and television.

81. Group B consists of operations that set up economically beneficial in-orbit production and that put into orbit production that is necessary, but dangerous when performed on the ground. Setting up such operations will require the expansion of ground-based and, primarily, space-based experiments that seek reliable, efficient in-orbit technologies and that conduct research that seeks a niche in ground-based economics that could naturally use orbital production.

82. This group could include operations involving research on the feasibility and advisability of the creation of orbiting solar

electric power plants that supply Earth with cheap, ecologically clean electrical energy.

83. It could also include operations on orbital stations involving research on the most effective activity of people working in orbit.

84. Group C consists of operations that maintain peace on Earth, that maintain stability and reinforce trust between states, and that prevent aggression.

85. That involves the creation of an international satellite system, open for everyone, for observing and monitoring land and ocean surfaces and monitoring air space and underwater activity.

86. Right now, it's almost just the Soviet Union and the United States who have satellite reconnaissance systems, which, by the way, still do not have all-weather capabilities and do not provide pictures of high enough quality at twilight or at night. Thus, it is being proposed that systems of satellites be created that would make it possible for everyone to see what is happening on Earth during both the day and the night, to monitor movements of troops and equipment and the construction of suspicious (possibly military) facilities, and to monitor the observance of international agreements.

87. Today's space hardware, in theory, can handle that task, and what's important is that the expense of creating and operating such a system could be borne by the world community.

88. There is, of course, something dishonorable about spying on each other. But what can we do in these times? The twentieth century has shown us more than once how criminals and maniacs have sometimes seized power. And that after strengthening their positions within a state by terrorizing and roughing up their own countrymen, they have made brazen attempts to seize neighboring states.

89. An international monitoring system would make it possible for all interested parties to monitor suspicious movements, construction, and preparations (after all, no enterprise begins operation spontaneously-it undergoes preparations, which can be noted) and to cool the ardor of gangsters who have elbowed their way to power. It would also enable the world community to take timely measures for repelling aggression or even halting preparations for it.

90. 2. Study and exploration of the solar system. Although such studies would hardly provide us with any fundamentally new information, it would simply be unintelligent not to study what is right under our nose. The scale of such operations is another matter.

This area includes studies of, for example, the Sun, asteroids, the Moon, Mercury, Venus, and Mars, Jupiter, Saturn, and their satellites and studies of the feasibility and advisability of space settlements. Such operations can hardly be considered to be of prime importance, but they shouldn't be neglected. The studies can be done with unmanned space vehicles. And only if the delivery of soil and air samples from Mars were completely unsuccessful or if we got information indicating that living organisms could be found on Mars would it be worth it to seriously consider organizing a manned mission to that planet.

91. It is implicit here that soil and air samples would be brought back to Earth for studies that would determine whether they contain living organisms, and if so, the studies would identify their genetic code or their mechanism of reproduction and thereby obtain information that would support a given hypothesis about the origins of life on Earth-whether it was ''self-generated,'' or ''seeded.''

92. 3. Studies of the Universe. These studies represent extremely interesting areas of study, areas that, one could say, stir the imagination. They are capable of providing us with very valuable, unusual information.

93. Such operations include studies performed with space telescopes placed in circumsolar and near-Earth orbits and working in conjunction with interferometry; studies of the world around us, done with state-of-the-art orbital astrophysical instruments (on the scale of the Hubble space telescope) in various spectral ranges; very long baseline studies with optical telescopes that could be placed on the Moon, for example; and studies of flight to the stars.

94. The Space Hardware of the Near Future

95. Effecting such a program of operations will require that existing space hardware be improved, that completely new hardware be created, and that theoretical and experimental research be done.

96. One would imagine that the following hardware will be required.

97. 1. Low-orbit systems of standardized satellites for environmental monitoring, natural resource studies, and weather observations, with ground-based computer centers for processing information and a computerized system for delivering the results to subscribers.

98. There is a great deal of completed research in this area already on hand, especially in the United States. Those operations should be extended to a commercial basis. Our country could also take an

active part in the creation of such systems.

99. 2. A system of platforms in geostationary orbit for global communications, television, environmental monitoring, natural resources studies, and weather observations.

100. A geostationary orbit is an orbit lying in the equatorial plane at a height of about 36,000 km above the surface of the Earth. Satellites in geostationary orbit do not move in relation to the Earth's surface. We shouldn't place too many communications satellites in that orbit, because they would begin to interfere with each other's work. That is why, in the future, we will probably have to create multifunctional platforms that expand their capabilities.

101. 3. Orbital stations, which should probably be created in various versions:

102. station/laboratories like Salyut and Mir

103. stations like the American space station Freedom, which is currently under development

104. orbital ''cloud-stations''.

105. I think the last type of station is most promising. The concept of a cloud-station consists in the individual parts of the station-its modules-not being connected to one another in a rigid fashion, but ''floating'' near one another.

106. 4. Orbiting factories for the production of ultrapure materials and biological preparations and for other production processes that will be profitable or better done in orbit.

107. 5. Unmanned space vehicles that are part of an international satellite system for observing and monitoring land, sea, and ocean surfaces and air space and underwater activity, with a system for sending the information to subscribers.

108. The international monitoring system could have three subsystems: 12-16 satellites with optical/television gear for daytime observations; 12-16 satellites with radars for all-weather and round-the-clock observation of land and ocean surfaces, air space, and underwater activity (monitoring of submarine movements); three-six satellites with gear for monitoring in the infrared range.

109. Today's optical/television space systems are already making it possible to look at objects from orbit that are on the order of a meter across and to transmit the images of those objects to

subscribers via relay satellites.

110. If power is high enough, so-called side-looking radars that are satellite-borne make it possible to perform round-the-clock, all-weather observation of the surface of the Earth and the air and even to monitor the movements of submarines. In theory, orbital radars could be use to differentiate between objects that are just a few meters long.

111. Such a system of satellites could be used to update information on what is happening at the Earth's surface every 30-60 minutes.

112. 6. Systems of radio telescopes placed in near-Earth and circumsolar orbits and operating as part of a single interferometry network. Radio telescopes taken to circumsolar orbit could be used to obtain a resolution in the ten-millionths of a second of arc and to peer to the very edge of our Universe.

113. Moreover, large radio telescopes on the order of a kilometer in size would enable man to begin a regular search for signals from extraterrestrial civilizations.

114. 7. Orbital astrophysical observatories working in various spectral ranges.

115. 8. If theoretical research confirms the wisdom of creating optical telescopes with mirrors spaced considerable distances apart, then it may turn out that they would best be placed on the Moon. The idea behind such telescopes is the same idea used in radiointerferometry-increasing the baseline of observation. But that baseline must be maintained and must be known with an accuracy down to tiny fractions of the wavelength of electromagnetic radiation at which the observation is being made, i.e., in this case, with an accuracy to fractions of a micron. That is where the idea came from to place them on the Moon.

116. 9. The need could arise to create a lunar base that could be used as astrophysical observatories on the surface of the Moon and as a base for studying the possibility of using lunar minerals in man's space-based activities. But the wisdom of opening operations in that area will, in my opinion, require additional consideration in the coming decades.

117. 10. Unmanned vehicles for bringing Martian soil and air samples back to Earth.

118. 11. If, as a result of those operations, it becomes necessary to perform a mission to Mars, then we will have to develop and build

the appropriate systems for a manned mission: Mars orbiter and Mars mission module, a Mars ''automobile,'' and the appropriate gear for living on Mars and doing research there.

119. 12. Unmanned systems for studying Venus, an orbital base near Venus, atmospheric balloon-probes, systems for performing radar mapping of the surface, and landable laboratories.

120. 13. Solar observatories with the perihelion inside the orbit of Mercury; they would be intended for studies performed on a regular basis of the star closest to us-our Sun.

121. 14. Unmanned vehicles for studies of the asteroids.

122. 15. Unmanned space vehicles for studies of the distant planets.

123. 16. Truly inexpensive, reusable transport craft for transport operations between Earth and orbit.

124. Neither the American Shuttle nor the Soviet Buran is capable of solving the problem of lowering the transportation costs in space. Right now, the cost of putting payloads into orbit with the Shuttle system is about $10,000 per kilogram payload-that is much more expensive than even with the old, expendable launch vehicles. Which means that the problem of creating truly inexpensive systems for putting space vehicles into orbit is still with us. In my opinion, such new systems should be able to lift space vehicles into orbit at a cost of somewhere in the hundreds of dollars per kilogram. That will be a difficult problem, but we can solve it with today's technology.

125. 17. Inexpensive reusable transport systems for transport operations between low orbit and geostationary orbit.

126. 18. Space robots. We should expect an expansion of operations in open space in Earth-satellite orbits. Such operations will involve the creation of orbiting factories and large radio telescopes, the maintenance of orbital vehicles, and possibly the construction of orbiting electric power plants. The difficulty of movement experienced by individuals clothed in the armor of a space suit and the dangers of working in open space will compel us to develop space robots.

127. Below, individual areas of operations are examined.

128. Orbital Injection Systems

129. The main thing we have to do is create truly inexpensive

reusable systems for placing space vehicles into orbit.

130. At the moment, the cost of putting space vehicles into orbit is extremely high. That stems from the high cost of rocket engines, the complex control system, the expensive materials used in rocket and engine structures, and, primarily, their one-time use. It was natural that as early as in the 1970s, someone got the idea to create a reusable injection system.

131. The first bit of experience that was acquired in implementing that idea was the creation of the Shuttle system. In spite of the marvelous work that was done, that experience can hardly be called successful. In the original project, the cost of a launch of the system was not to exceed a sum on the order of $10 million. But that was too optimistic an estimate, and in years past the cost of launching the system has fluctuated between $150 million and $350 million. The main reasons for that are these: the use of a considerable number of expendable elements in the structure; a very complex design and, accordingly, complex preparations for launch in which a great many specialists must take part. It must be said, of course, that the analogous Soviet Buran system is no better than the Shuttle system in that regard.

132. That is why the creation of a truly reusable, truly inexpensive system for placing space vehicles into orbit remains an urgent task. In that connection, a solution to the problem may be sought in two directions.

133. The first is rather trivial: create a reusable, single-stage, oxygen/hydrogen rocket with a highly advanced design. That rocket would go into orbit, deposit the space vehicle there, and then descend from orbit, decelerate in the dense layers of the atmosphere, and make a landing in the vicinity of the launch. That would be possible if we managed to develop a design in which the mass of the tanks, the engines, the heat shield, the return rocket's landing system, the control system, and the space vehicle itself that is being placed into orbit did not exceed 10-11 percent of the launch mass. That would require ultrastrong, ultralight materials, plus very light engines, heat shield, and landing system. The task is a very difficult one, and there are a number of design ideas for resolving it, but they require additional research and analysis.

134. The other means of solving the problem is revolutionary. It is based on the principal shortcoming of today's rockets: their tanks contain not only propellant, but also oxidizer (which must also be lifted), even though a segment of the flight is through the dense layers of the atmosphere, where oxygen is quite abundant and would seem quite logical to use. But that's not incidental-use of

atmospheric oxygen on the rocket would require air-breathing jet engines, in addition to liquid-propellant engines (a large segment of the flight still proceeds outside the dense layers). And they're much heavier than liquid-propellant engines. But new possibilities are now appearing in that connection. Today, the creation of combined engines that operate in air-breathing jet mode in the initial part of the flight, at speeds of up to 1500-1700 m/s, and then switch to liquid-propellant mode, is becoming a reality. That could provide a considerable advantage in launch-vehicle mass and size.

135. Those ideas apparently formed the basis of the English project Hotol. That airplane is supposed to take off from an airport, aided by a special launch chassis that remains on the ground. It then accelerates to an altitude of around 25 km with an engine that takes in oxygen from the atmosphere. At that point, it is traveling at a speed of about 1600 m/s. After that, the flight is performed with onboard reserves of oxygen. Liquid hydrogen is proposed as the propellant for both segments of the flight. According to the design, Hotol, with a launch mass of around 200 tons, is supposed to place a payload of around 7 tons into orbit and then return to Earth. Judging from the articles in the press, the work on the project has been halted-there's no financing. It is difficult to judge the feasibility of the project, because that feasibility hinges almost entirely on the feasibility of proposals involving the creation of a lightweight combined engine capable of operating in an air-breathing jet mode and a liquid-propellant mode, but almost no materials have been published on its working principle. The engine was developed by the well-known English firm, Rolls-Royce.

136. Work is being done in other promising directions. The German Sanger project also calls for the creation of a completely reusable two-stage system. The first stage is supposed to use air-breathing jet engines, and the second stage, liquid-propellant engines. After expending its fuel, the first stage is supposed to return to the airport. The second stage, after placing the payload into orbit, returns to Earth and is readied, along with the first stage, for the next flight. But the data cited in the press on the estimates of the mass characteristics of the components of the system have raised some doubts as to the soundness of the characteristics.

137. An even more revolutionary direction is being pursued at present in the United States. It is based on the idea of the creation of a ramjet engine capable of operating at speeds of up to around 7.5 km/s, i.e., virtually the entire process of acceleration of the rocket-airplane is done in the atmosphere, and almost no oxidizer is carried in the rocket. The basic research, as far as one can tell, is aimed at studying the possibility of creating such an engine.

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138. Orbiting Solar Electric Power Plants

139. One possible direction in the development of space-based operations to meet the basic needs of mankind involves the creation of orbiting solar electric power plants for supplying energy to ground-based consumers. Solar energy can be converted into electrical energy in various ways. But the simplest and most natural for our purposes is to use semiconductor converters that transform sunlight energy into an electrical current, i.e., solar panels. We have already accumulated experience in their long-term operation in space. Silicon cells are usually used as the converters-thin, small (several centimeters square) wafers in which a potential difference arises as a result the photoeffect that is produced when sunlight strikes them. Only a very small amount of power is derived from one such cell. The energy conversion efficiency in such a converter is on the order of 10-12 percent. To make a practical power-supply source out of those cells, they are linked in a series-parallel circuit. As a result, from one square meter of solar panel, one can obtain a quantity of power on the order of 140-170 W. Of course, such panels produce a current only under solar illumination, and such a level of power is produced only if the Sun's rays are perpendicular to the surface of the panels. That is why on many space vehicles, special systems orient the solar panels to increase the derived power. When the vehicle passes in the shadow of the Earth, the instruments and equipment get their electrical power supply from storage batteries that had been recharged by the solar panels when the vehicle was outside the shadow.

140. Orbiting solar electric power plants would be useful for supplying Earth with electrical energy. The electrical energy produced by the solar panels could be transformed into radio waves and transmitted in the form of a narrow beam to a receiving antenna on the Earth's surface by the pencilbeam antenna of the orbiting electric power plant. The waves received on Earth could then be reconverted into electrical energy and sent to consumers. In order for orbiting electric power plants to have continuous and immediate communications with ground receiving stations, the orbiting plants are best placed in geostationary orbit.

141. The most important thing in the creation of orbiting solar electric power plants is to master building in space gigantic structures that must be lightweight and steerable in orbit. We could begin, for example, with the assembly of an openwork panel unit that is, say, 100 x 100 x 100 m. And then, by gradually linking such units to one another, we could increase the area of the structure to dozens of square kilometers. A panel 100 sq m in area could derive as much as 10 million kilowatts of power. Transmitting the energy back to Earth from such an orbiting electric power plant would require an

antenna nearly one square kilometer in area. The ground-based receiving antenna would have to have a diameter on the order of several kilometers. It would probably be best not only to assemble the components of the panel units in orbit, but also to manufacture them in orbit. That is, to put, say, rolls of metal ribbon into orbit, cut it up there, and make rods from it, which would be used then to assemble trussed panel structures. Of course, other technologies for manufacturing and assembling the panels could also be found.

142. Needless to say, today's solar panel sheets couldn't be installed on those gigantic structures-they would be too heavy and expensive, because a square meter of solar panel has a mass of several kilograms. In recent years, however, a modicum of success has been achieved in the creation of film-type solar panels, a square meter of which might have a mass of only several hundred grams. In light of the mass of the trusses and other components of the structure, the adjusted mass of a square meter of panel on the solar electric power plant must be roughly a kilogram per square meter of panel and, consequently, about 10 kg per kilowatt of installed power (the mass must be that so that the creation of the solar electric power plant would be profitable, and that is achievable). A kilowatt of power produced by the orbiting power plant would then cost about 2,000-3,000 rubles (assuming the transport problem is solved). That is one and a half-to-two times cheaper than power from nuclear electric power plants, two-to-two and a half times cheaper than power from hydroelectric power plants, and four-six times cheaper than power from fuel-fired electric power plants. Orbital electric power plants, however, do not use up natural resources, and after several years of operation, they can be more economical than fuel-fired or nuclear electric power plants. And the main thing is, such plants would be ecologically clean.

143. The most difficult problem surrounding orbiting solar electric power plants is the problem of putting the materials into orbit for the construction of the plant. The mass of a 10 million kW plants would be around 100,000 tons. Solving that problem would require the creation of a completely new type of reusable launch vehicle. On one hand, it would have to be a rather large vehicle capable of lifting a payload of, say, around 500 tons, so that the construction materials for one plant could be put into orbit within two or three years (with 70-100 launches a year) and the construction could be effected with the same speed. On the other hand, if the undertaking is to be economical, the cost of a launch with such a vehicle must be no more than 50 rubles per kilogram of payload. If you compare that figure with the figure for the cost of using the Shuttle system to put a payload into orbit (on the order of $10,000 per kilogram), the difficulty of the problem becomes clear. The launch cost must be

reduced by two orders of magnitude. The task, however, is not a hopeless one. In economic terms, the Shuttle system is an order of magnitude more expensive than even today's expendable launch vehicles. And reducing spending by an order of magnitude by switching to a new type of reusable launch vehicle is not impossible. Of course, at the same time we would have to also solve the problem of moving materials that had been placed in a low intermediate orbit to a geostationary orbit.

144. And on that segment of travel, the expense would have to be about the same, i.e., for that segment we would also have to create cheap reusable systems that would probably use solar panels and electric engines.

145. Orienting the gigantic trusswork panels toward the Sun is a problem that is entirely solvable. After all, in practical terms, we would have to rotate the panel at a constant rate equal to one revolution per year.

146. Building the power plant in orbit would require specialized production. It would require builders. They would need housing-orbital stations. Of course, all production would have to be as standardized and automated as possible. The construction would have to be done primarily by robots. Which is why there would be only a few people there. They could work in orbit for, say, no more than a year per ''tour,'' which would mean that artificial gravity would not be needed on the builders' stations.

147. There are, of course, many other problems associated with the creation of orbiting solar electric power stations: the conversion of enormous outputs of electrical energy to radio waves, the onboard directional antenna with a diameter of about a kilometer, the systems for receiving the powerful stream of radio waves and converting them back into electrical energy, etc. But all those problems are in the realm of reality.

148. Space-based electric power plants are attractive because they can make a substantial contribution to the solution of one of the most difficult problems facing mankind today-the creation of ecologically clean power engineering. This is not an attempt to convince the reader that orbiting solar electric power stations represent the only sensible means of solving that problem. It cannot be seriously compared with any other until competitive projects as such are developed. But it is one possible, hopeful solution.

149. Orbiting Factories

150. Automated factories in orbit are promising and feasible.

Weightlessness and the vacuum can be used to advantage in the production of the ultrapure preparations and materials that are needed in today's medicine and in industry. Of course, there cannot be absolute weightlessness on orbital vehicles-it exists only in the center of mass of the vehicle. But at points meters away from the center of mass, the accelerations are only a millionth of the acceleration due to gravity on Earth. And the vacuum is not at all absolute in orbits with an altitude of around 500 km. Nevertheless, both the accelerations due to microgravity and the pressure of the ambient atmosphere at such altitudes are rather low, which creates good conditions for certain types of production. The low accelerations due to microgravity make it possible to virtually eliminate from separation and crystallization the influence of the convection associated with the splitting of components in a mixture by the force of gravity and to dramatically reduce the number of defects formed in crystallization. Experimental operations that have been performed on orbital stations, manned spacecraft, and unmanned space vehicles in the context of research on the efficiency of various production processes in orbit show that the quality of the processes is improved in weightlessness. But we have yet to achieve a level that enables us to draw definite conclusions and begin designing orbiting factories.

151. Areas that hold promise today are those that involve production processes associated with the purification of biological preparations on electrophoresis units of any kind for the pharmaceutical industry, processes associated with the growth of crystals of materials used in the electronics industry, processes associated with raising the purity and relative mass of output of a product, and processes associated with the production of optical glass fiber for fiber optics, which in orbit can yield better products and can be more economical than can ground-based production.

152. Radio Telescopes

153. Radio telescopes in near-Earth orbits or, what is more effective, in Sun-satellite orbits may be one of the most effective means of studying the Universe. With receiving antennas that are hundreds of meters in diameter, radio telescopes can detect signals from objects that are at the edge of our Universe. If observations are made with several radio telescopes spaced across a distance on the order of the diameter of a solar orbit, the principles of interferometry can be used to produce, as mentioned earlier, an absolutely fantastic resolution in the ten-millionths of a second of arc. The size itself of receiving antennas that are hundreds of meters across need not be disturbing-the erection of structures of such dimensions in weightlessness is entirely feasible with today's technology. The main problem would be ensuring precision of surface

of the antenna. After all, the precision must be to a fraction of the wavelength at which the measurements will be made. For example, for observations made at 20 cm, the precision of the surface would have to be such that it is measured in centimeters for a structure a kilometer across! And the thermal deformations of the structure would also have to be in the centimeters. The problem, it seems, would have to be solved by using adjusting elements and a laser measuring system.

154. The Cloud-Station

155. The idea of a cloud-station owes its existence to the difficulties associated with the creation and functioning of large structures such as the American orbital station Freedom, which is under development at this time. Such difficulties include the following:

156. the enormous size of the trusswork structures that hold the living quarters, fueling stations, production facilities, telescopes, solar panels, and transport craft, which results in enormous moments of inertia and in difficulties in orienting such structures

157. excessive programming of such stations, which limits the possibilities for developing and improving production and research programs

158. the inclusion of production facilities in the same structure as the other facilities leads to an increase in the levels of microgravity in the production facilities, which in all likelihood would have an effect on the quality of the product being made and would require restrictions on orientation and control of motion and on crew activity

159. the operation of first-class telescopes requires attitude control with an accuracy to within hundredths of a second of arc, which would probably be impossible for the entire structure, even if freedom of angular movement relative to the station structure were provided for the telescopes

160. the inclusion in the station structure of fuel containers that generally hold hypergolic components and a complex pneumohydraulic system for taking on fuel from refueling craft and for distributing it to the users in the station is not without danger and is to be considered undesirable.

161. On the other hand, it is natural to locate all those facilities near one another, in order to be able to adjust, repair, test, and maintain all the telescopes, production laboratories, plants, and

fueling stations.

162. Those difficulties and contradictions can be eliminated by using a cloud-station system. Imagine a station consisting of several autonomous units-for example, the living quarters base unit, an astrophysical observatory, a production/laboratory module, and a fueling module. All the units are flying in the same orbit, not too far from one another, such that the distance from the base unit to any of the other units is always within a certain range (say, 10-100 km). To accomplish that, each unit needs to have a system for measuring distance and radial velocity relative to the base unit and a propulsion system with motors for making coordinate shifts.

163. The pattern of action is rather simple here. The rate at which a unit moves away or approaches is reduced to a minimum that is determined by the sensitivity of relative velocity meters. Assume that it is 1.5 cm/s. Then the distance increases to 50 km from 10 (depending on the features of the motion of the satellite in orbit) over a period of roughly nine-10 days. When the distance nears 50 km, the outer unit fires an impulse that changes the sign of the relative velocity, and the unit begins to approach the station and pulls up to within that original 10 km within another nine days, etc. If the relative velocity is measured with an accuracy on the order of a centimeter per second (which is quite realistic for today's radars), then the amount of fuel required for keeping the units of the station in a given relative position is considerably less than the amount we must use in any case to compensate for the atmospheric drag on the station. Thus, the telescope, for example, can be kept 10-50 km behind the base unit, with the production module 10-50 km ahead and the fueling module still farther ahead, say, 60-100 km from the base unit.

164. The makeup of such a cloud-station could expand and change. It would be natural to use the base unit of the station, where the duty shift of cosmonauts are located, also as a geophysical module, with gear for environmental monitoring, for studying natural resources, etc. Hardware for medical and biological research could also be located there.

165. The base unit would also have several docking positions for manned spacecraft and cargo resupply craft and for orbital ''cars''-vehicles designed to fly the cosmonauts between station units for maintenance purposes.

166. The Lunar Base

167. Without concerning ourselves with the question of the timeliness or level of priority associated with the creation of a

lunar base in the coming decades, let's try to imagine what it would look like and how much work would be done there. (We intend to publish a brochure on lunar base projects in the near future.-Ed.)

168. The tasks performed by the lunar base could include regular studies of the Moon (seismicity, meteoritic conditions, structure, geology, exploration for lunar minerals useful to man), empirical verification of the possibility and advisability of mining minerals, and construction of an astrophysical observatory if further studies demonstrated the advisability of creating one on the Moon, where the absence of an atmosphere, the low gravity factor, and the possibility of installing telescopes on immobile foundations would seem, at first glance, to offer important advantages over Earth-based and orbital telescopes.

169. The last task could turn out to be a rather important one, especially if we manage to demonstrate the possibility of building synthetic-aperture telescopes with reflectors spaced as far apart as possible.

170. The base would naturally have an information-and-control center, laboratories, separate cabin-apartments for the base workers, areas for physical exercise, a messroom, a wardroom, and a kitchen; an airlock/hangar for servicing and repairing lunar rovers; production facilities; a power plant; systems for life support and temperature maintenance; a greenhouse; warehouses for things like spare parts, fuel, and collected samples; lunar rovers for research expeditions, transport vehicles, and hangars for them; and hangar/shelters for on-duty emergency evacuation craft.

171. Since the flight of a transport craft and crew to the Moon could cost around $1 billion, such a mission would naturally be geared to a lengthy stay by the specialists at the base. In addition, we would need to take into consideration the isolation and the psychological stress associated with working at the base. For that reason, we will need to provide rather comfortable living and working conditions for the lunar base crew. The crew would best consist of five or six individuals, each with two or three specialties.

172. Each crew member would need to have a separate cabin, 50-100 cu meters, with all the conveniences. In addition, there would have to be backup living quarters for overtime work and for emergency situations. Roughly the same amount of space would have to be earmarked for the main and backup information-and-control centers, laboratories, gyms, messroom, wardroom, kitchen, and production facilities. The total amount of space for the pressurized areas, including living quarters, could be around 2,000 cu meters. In light of the the theoretically ever-present danger of depressurization,

fire, or contamination of the atmosphere with harmful gases, the pressurized spaces would have to be sectioned off and each section would have to have emergency entrances and exits. Pressurized spaces would best be shaped in the form of a cylinder 3-4 m in diameter.

173. Then there is the question of protecting pressurized spaces from meteors and from the large temperature differential on the lunar surface as day turns to night. We could, of course, use measures that are typically used for orbital space vehicles-screens and screen-and-vacuum insulation. But on the Moon, it would probably be more natural and more effective to bury the station structures in the ground and cover the top of the station with the excavated soil. Before the top of the station is covered, naturally, everything would have to be finished-e.g., all the structural assemblies, all the mainlines, all the plumbing, all the cable systems. The giant structures that make up the stations quarters cannot be transported from Earth in finished form. It would make sense to take up pre-cut sheets for enclosures-plus ''semifinished products'' in the form of frame parts, hatches, and, among other things, ''pipe-jacket'' reducers-and then to use, mostly, robots for doing the welding right at the prepared construction site for the base.

174. It is clear that construction of the base would have to be preceded by a lunar reconnaissance mission that surveys the area chosen for the construction of the base and brings construction equipment (scrapers, crane excavators) and construction materials from Earth. There would have to be, obviously, a landing of several construction missions to prepare the construction site (ground work), roads, and landing areas for cargo resupply vessels and manned spacecraft and, finally, to do the construction itself. And that, in turn, means that a temporary station would have to be brought up for those who are building the base.

175. The information-and-control center must be the conduit for information from Earth, from lunar rovers with researchers aboard (who may be hundreds of kilometers from the base, i.e., far beyond its visible horizon), and from workers who may be outside pressurized compartments at any given time, plus telemetry from onboard base systems. All that means that in order for the on-duty operator to be able to identify the current situation, there must be completely automated, computer processing of all incoming information, with output of correlated evaluations of the situation as a whole and of the situation for each distinct system and for each individual outside the base. The results of the analysis must presented clearly on electronic boards and displays, and recommendations must be given to the operator. Thus, powerful software must be created to replace the hundreds of specialists who work in flight control centers, analyzing already processed information and preparing recommendations

for flight directors and cosmonauts. Of course, in theory, we could preserve the system that has come about for analyzing situations that come up on manned spacecraft missions and the system for arriving at a decision in the ground-based flight control center. But in a decade or two, such systems will probably be declared to be not reliable enough and too expensive.

176. For telephone and television communications with lunar rovers that are beyond the base's radio horizon, we could use lunar relay satellites or base/Earth-relay/lunar-rover and lunar-rover/Earth-relay/base links. Communicating through an Earth-based relay would be awkward, because there would be a time lag of about five seconds. We will apparently have to use both versions, because a lunar relay satellite won't always be in the radio horizon of the base and the lunar rover. Naturally, the information-and-control center must have telephone and video-communications systems, with all the necessary working space and living space, as well as outside areas (fueling station, power plant, landing areas, etc.). In addition, provisions must be made to ensure that the space outside and the surrounding area can be surveyed with television cameras.

177. The problem of power supply to the base is complicated by the fact that the two-week day will be followed by the two-week night. Therefore, if the power-supply system is based on solar panels, then the problem of where to get energy at night must be solved right away. Even if a ''hibernation'' mode is used by the station, that will require storage batteries weighing many tons. Besides, going into hibernation for two weeks out of every four would be inefficient.

178. To be able to use as storage devices water-electrolyzer systems that work during the day to store electrical energy and electrochemical generators that work at night to output the energy would require the creation of giant installations with enormous gas tanks for hydrogen and oxygen.

179. A suitable solution would probably be to use a small nuclear electric power plant (more precisely, two or three power-generating units set apart from one another). The generating units would have to be brought to the Moon in finished form (but not switched on) as priority cargo for the construction of the base and would have to be one of the first things to be installed.

180. The temperature-regulation system will have to ensure acceptable conditions that are fairly comfortable for the base's crew in terms of the inside temperature and conditions that are acceptable for gear and equipment in pressurized and nonpressurized station

facilities during the day and the night. Thermal insulation and the radiator removal of excessive heat solve that problem during the day. But night will require heating. The heat source will probably have to be the heat given off by the nuclear power-generating units or the heat from isotope heaters. In addition, the system will have to collect moisture from the air of the inside spaces of the base.

181. The high cost of delivering supplies to the Moon is the reason that closed-loop life-support systems will be used as much as possible. It would be difficult for everything to be in a closed-loop system, but water and oxygen could certainly be in a completely closed-loop system if electrolysis of water collected from the air, urine, and carbon dioxide were used. Nearly 300 kg of dehydrated food and about 100 kg of expendable materials would have to be taken for each individual per year. Such a system would have to be included in the base's equipment. But, of course, we need to try to solve the closed-loop problem for food, too. That would take complex equipment, higher levels of energy use, and more space. The task of creating a closed-loop system for oxygen, water, and food must be included in the programs of operation of space hardware for the coming decades. A closed-loop system for oxygen and water only would require about 300-400 W of electrical energy per person (i.e., about 2.5 kW for that one system alone). Of course, there must also be emergency reserves of oxygen, water, and food.

182. Life-support gear would include gear that would be brought up to the Moon, namely the following: clothing, underwear, and footwear; replacement parts for things like autonomous life-support systems, EVA suits, lunar rovers, tractors, and crane hoists; medical diagnostic and treatment gear; and exercise machines.

183. The base, naturally, would have to have advanced transport vehicles: lunar rovers for research expeditions, trucks, scrapers, portable drilling installations, excavators, etc.

184. At this point, it seems that it would be wise for the base to also have an on-duty evacuation craft to be used in the event of an emergency at the station.

185. And finally, the main thing is that equipment for scientific research and exploration must be developed.

186. A serious estimate of the mass of the base structures that will have to be delivered from Earth and an estimate of the costs will be possible only after formulation of the project gets under way. Preliminary estimates put the figures at about 100 tons for the mass and around $100 billion (or 100 billion rubles) for the cost of the operations to create the station.

187. The Mars Mission

188. The very first question that comes up is, Why? Exactly why do we need to be undertaking such a grandiose enterprise right now? There are no convincing arguments for it. Just the opposite-one can easily see an element of children's logic: ''It's a place we can reach and visit-so we need to go there!''

189. Here are the facts:

190. Mercury would be harder to reach (the trip would take a great deal of energy), and it's too hot there, and there's no atmosphere, and there's nothing to do there, as it were-it's the same rocky desert as on the Moon.

191. Venus, to put it mildly, is too hot at the surface (450-500°C), and the pressure would be absolutely unbearable (100 atm), so we couldn't land there.

192. Jupiter, Saturn, and the planets beyond are even worse and more complex-it would take much more energy to get that far, and the force of gravity is greater, and the atmosphere-don't even mention it.

193. But Mars-that's another matter. The gravity at the surface is 0.4 Earth gravity. The atmosphere, although quite rarefied, still exists. And the temperatures are not as severe as on the Moon.

194. In a word, Mars is more natural and more accessible.

195. But what is still not understood is this: Why do we need to send a mission there? ''How can you ask that?'' answer the proponents. ''We're going to have to colonize Mars sooner or later.'' But why do we need to colonize Mars? It's clearly not suitable for human life. We could see setting up a base on Mars (if and when we see that it's needed), but it's hard to imagine a need to colonize it.

196. And yet, there is one problem whose solution could justify sending a mission to Mars-the search for life on that planet. There is some basis for hope (however slight it may be) that life exists: there are the remnants of an atmosphere, and photos of the surface of Mars show traces of water erosion. Might there not be simple organisms there, life on the level of, say, bacteria or fungi? Those living organisms themselves would not, in fact, be of as much interest as would the mechanism of their reproduction. What kind of mechanism would that be? The same as on Earth (and on Earth, from the standpoint of the organization of that mechanism, we are all-plants

and animals-relatives)? If the mechanism were identical, the hypothesis of the ''seeding'' of life throughout the Universe would be probable (it wouldn't be absolute proof-it would be one experimental point). If the mechanisms turned out to be completely different, the theory of the self-generation of life would be essentially confirmed.

197. Of course, it would be natural to try to ''catch'' living organisms with unmanned vehicles that landed on Mars. Such vehicles have been landed, but nothing has come of it. And there have been too few points of collection of samples, and the procedures themselves of analysis of samples for ''life'' are not very conclusive.

198. The Mars mission could be a continuation of the work done with unmanned vehicles. Possible tasks for the mission could be the exploration and study of areas of the Martian surface where there is some sort of chance of finding signs of life, a search for living organisms or plants, the collection of soil samples (at various points on the surface and at various depths) and air samples, an initial, on-site study of such samples (so that the research program could be adjusted in the event of positive findings), the delivery of the soil and air samples to Earth, and the study of the surface of Mars, the planet's structure, and the planet's natural history.

199. The equipment for a Mars mission would be determined largely by the primary operations performed during the mission and by the mission profile itself. For a Mars mission, it would be natural to adopt the basic profile used for the American lunar mission: trans-Mars injection from Earth satellite orbit, flight to Mars, Mars orbit insertion, descent to the surface of Mars of the mission module with some crew members (the others in the crew would remain in the orbiter in a Mars satellite orbit), research on the planet surface, collection of soil and air samples, return of the mission module to satellite orbit, rendezvous and docking with the orbiter, transfer of the landing party to the orbiter, trans-Earth injection from Mars satellite orbit, return of the mission to Earth.

200. Two components immediately become distinct: the orbiter and the mission module. Their appearance depends substantially on the amount of fuel needed for performing the dynamic operations associated with changes in the velocity of motion of the two craft. The amount of fuel spent in a given dynamic operation is determined by the magnitude of the required increase in velocity, by engine quality, and by vehicle mass. That is why in the process of analysis, before the choice of design profile or type of engine, the energy expenditures are usually characterized in terms of the increase in velocity of a vehicle (with the integrator) for the various stages of the flight.

201. Those expenditures tentatively appear to be the following for a Mars mission spacecraft:

202. 1. Injection of the complex from an Earth satellite orbit to a trans-Mars trajectory: 3.6-4 km/s (depending on how close it is to the optimal date for injection).

203. 2. Expenditures for the orbiter:

204. insertion into Mars satellite orbit: 0.1-1.5 km/s (depending on the method of orbital insertion and the orbital parameters chosen)

205. injection of orbiter from Mars satellite orbit to trans-Earth trajectory: 0.5-1.5 km/s (depending on Mars satellite orbit parameters)

206. insertion into Earth satellite orbit: 0-3.2 km/s (depending on return profile chosen-either with immediate reentry, or with a preliminary ''stop'' in Earth satellite orbit).

207. 3. Expenditures for the mission module:

208. descent from orbit into a descent trajectory, plus landing: 0.2-/3 km/s

209. insertion from Martian surface into Mars satellite orbit: 5.3-4.2 km/s (depending on parameters of orbit in which orbiter is waiting)

210. rendezvous and docking with orbiter: 0.1-0.2 km/s.

211. Those data show that a great deal is considerably more accessible and determinable for a Mars mission spacecraft. The power needs and the appearance of the craft can be described here and now.

212. The Mars mission module will have two propulsion systems: one on the lander (for the descent and landing), the other on the ascent stage (for orbital insertion and rendezvous and docking with the orbiter).

213. The operating conditions and the large number of cut-ins (the steering engines will have thousands) determine the fuel components: high-boiling-point, hypergolic-and, thus, toxic-components such as nitrogen tetroxide gas and nonsymmetrical dimethylhydrazine. The toxicity of the components represents a substantial drawback, especially since the cosmonauts will have to go out onto the planet's surface, which is ''flooded'' with the components. And besides,

something is wrong with things when people show up on planet where they're searching for life, and they begin by poisoning the landing site and the living organisms they're looking for in that area. Pragmatic considerations urge the use of reliable, convenient components that are toxic, and the reputations of the people associated with Mars missions have long been ruined: after all, just such components have been used in all the unmanned vehicles that have landed on the Martian surface. But it wouldn't be a bad idea to look for a nontoxic gas consisting of components that have a high boiling point (i.e., that are in liquid form at normal temperatures), are hypergolic (for purposes of reliability of operation of engines that cut-in tens, hundreds, or even thousands of times), and are sufficiently stable and shock-resistant. In theory, there is such a gas that comes close in terms of its characteristics to meeting those contradictory requirements: concentrated hydrogen peroxide and some kind of nontoxic hydrocarbon propellant with additives that ensure self-ignition with hydrogen peroxide. Additives to hydrogen peroxide (stabilizers) that will raise its stability still need to be found.

214. The lander must have equipment that is needed during the descent and during the mission's stay on the surface, but is not needed in the return from the surface to the orbiter: a forward heat shield used during the main deboost phase in the Martian atmosphere and jettisoned after the parachute system is triggered; the parachute system itself; a laboratory section for operations inside the craft on the Martian surface; electric-power generators (probably isotope generators); equipment for controlling the landing; a temperature-regulation system for the lander and the craft as a whole, which operates on the surface and includes heaters (probably isotope heaters) for the Martian night (as well as the Martian day); life-support system equipment and stocks (oxygen and water); an airlock and space suits for exiting the craft, with the necessary onboard equipment; systems for communications and television observation of the space outside; consoles and systems for displaying incoming information; a Mars rover that will enable rather extensive, long expeditions, with its own systems for things like electric power supply, life support, communications, and control and a system for temperature regulation; and research equipment (atmospheric probes, drilling units, analyzers, tthermostats, etc.).

215. Here the problem of the size of the laboratory section stands out-after all, the mission will have to work on the Martian surface for, maybe, several months. That means that dozens of cubic meters will be needed, plus individual cabins.

216. How many individuals will land on the surface of Mars? It would be expected that work will be done at the landing site at the same time that work is being done on the Mars rover. So the mission

module crew will have to consist of four people (two per team, so they can back each other up). If we must keep things to a minimum, then we can restrict the crew to two people, who both work at the landing site and then both make trips on the Mars rover. But that doesn't seem very intelligent: to fly somewhere that's worlds away and then restrict ourselves to some minimum amount of activity. Besides, the danger inherent in such a scheme of things raises some doubts about it. Now a compromise is under study: to have not one, but two Mars mission modules-one with a large laboratory section for work at the landing site, the other with the Mars rover. Their landings would be spaced in time, which would make it possible to use the second mission module to render assistance to the first if need be. And the crew of each would consist of two people.

217. The mission module would leave the Martian surface without the lander. In addition to a liftoff rocket system, the departing module would include a flight deck; gear for control, communications, telemetry, temperature control, and an electric power supply (probably based on chemical current sources, since autonomous flight without the lander won't be last long); life-support equipment for the crew; and a docking device.

218. The problem of communications between the mission module and the orbiter may prove to be a difficult one: only twice a day will the communications be what can barely be called satisfactory. And matters can be described as even more difficult when it comes to the need for communications between the mission module and the Mars rover when the rover is beyond the horizon. The problem can be solved by leaving the orbiter in a Mars-stationary orbit. The orbiter would be suspended in place over the surface of Mars, and its position could be over the landing site. Then, of course, there would be uninterrupted communications between the orbiter and the mission module and between the orbiter and the Mars rover and, consequently, between the mission module and the rover (through the orbiter). Such a version coordinates pretty well with a profile that uses an orbiter with electric engines.

219. The flight deck for the mission module could be rather small for two people-3 or 4 sq meters.

220. For the orbiter and the associated problems involving injection into a trans-Mars trajectory and injection from a Mars satellite orbit into a trans-Earth trajectory, there is no definiteness like that associated with the mission module. On the stages of flight between Earth satellite orbit and insertion into a Mars satellite orbit, the orbiter would include the mission module. The profile for a Mars mission would then look like this:

221. acceleration from a low, near-Earth orbit to a high, injection orbit (beyond the Earth's radiation belts), during which the spacecraft, without a crew, would take two or three months to move through the radiation belts (which is due to the low thrust capability of spacecraft with electric engines)

222. launch of the crew to the high, injection orbit by means of a special transport vehicle, rendezvous with the Mars mission orbiter, docking, transfer of the crew to the orbiter, separation of the transport vehicle

223. further acceleration of the orbiter to a trans-Mars trajectory with its electric engines

224. transfer to a Mars satellite orbit with its electric engines

225. waiting in orbit the return of the mission module

226. injection from Mars satellite orbit into a trans-Earth trajectory

227. direct descent of the mission crew to Earth and injection of the orbiter without the crew into a near-Earth orbit, again with the electric engines.

228. That profile involves large expenditures of energy, since with acceleration and braking during exit from planetary satellite orbit or insertion into satellite orbit at low thrust, the velocity characterizing the energy expenditure almost doubles. That is why if the use of typical chemical-fuel rocket engines with a thrust capability of around unity yields a total characteristic velocity of 4.5-7.3 km/s (including the energy spent for exit from Earth satellite orbit), then the use of electric engines produces a velocity of 9-14 km/s (depending on how good the injection dates are and what the Mars satellite orbit parameters are). In and of itself, that's not strange at all: the high velocity of the exhaust jet compensates for that drawback. Electric engines can produce an exhaust velocity of around 50,000-100,000 m/s instead of the 4600 m/s of even liquid-fuel oxygen-hydrogen engines. That is why the fuel needed for those operations is 9-24 percent of departure mass in Earth satellite orbit for a spacecraft with electric engines, but 63-80 percent for a complex with liquid-fuel rocket stages. In that context, one can see the very important advantage of electric engines: an increase in the final mass of the spacecraft (or in the mass of the Mars mission module) has little effect on an increase in the departure mass or, consequently, on the overall complexity of the undertaking in the process of its development and creation.

229. On the other hand, a spacecraft with electric engines has fundamental drawbacks: little experience has been garnered in long-duration operation of such engines, the spacecraft must have a powerful energy-supply system on board, and the service life of an electric engine is in the thousands of hours.

230. A departure mass of around 250-300 tons for a complex would require that a 7-10 MW electric power plant weighing around 70-100 tons be carried aboard the spacecraft.

231. Nuclear electric power plants have usually been considered, and added to the all the complications is the problem of providing radiation protection for the spacecraft crew and equipment at an acceptable mass. The problem is complicated by the fact that it must be solved not only for the flight of the complex as a whole (when the crew compartments and the section for the nuclear reactor do not move in relation to each other and, consequently, protection can be confined to the shadow shielding), but also for legs during which the mission module is departing from the orbiter and approaching it.

232. A spacecraft with a nuclear electric power plant and electric engines could take the form of a number of components located one behind the other along the spacecraft's longitudinal axis: the nuclear power plant, which includes the reactor and the shadow shielding that screens the rest of the structure and the living quarters from power plant radiation; the electric engines, with the propellant-feed system; the propellant tank; the trusswork connecting the nuclear power plant and the spacecraft compartments; the nuclear power plant temperature-regulation system radiator for the removal of heat unused in the converters that convert the heat produced by the reactor into electrical energy (geometrically, this is the largest part of the spacecraft); the compartments of the orbiter; the reentry vehicle used in the return to Earth; and the mission module.

233. Such a configuration for a Mars mission offers the advantage of the complex being extended along the longitudinal axis and the center of mass located in the vicinity of the connecting trusswork, and it would be relatively simple to produce artificial gravity in the crew compartments by rotating the complex around the axis perpendicular to the longitudinal axis (if artificial gravity were judged advisable for the crew of the Mars mission, which could last two or three years).

234. The problems associated with the power plant could change substantially if solar panels were used instead of a nuclear power plant. Solar panels with a total area of around 10,000 sq meters would be needed for an output of 7-10 MW. Solar panels could compete with a nuclear power plant only if the mass of the trusswork and the

solar cells themselves did not exceed 7-10 kg per kilowatt of derived electrical energy. That could be achieved if film-type solar panels with a mass of 100-200 g/m<sup>2<reset> and an efficiency of around 5-7 percent were created. Thus, film-type solar panels could become necessary for the Mars mission, for orbiting solar electric power plants, and for orbiting factories. Developing such panels is an urgent task for modern technology.

235. For a Mars mission that uses chemical-propellant jet engines only, choosing a mission profile that is optimal in terms of power needs is essential.

236. Such a profile would consist of the following:

237. injection of mission spacecraft into a low, near-Earth, assembly orbit, and use of transport craft to deliver the crew to the complex of mission spacecraft

238. injection of hydrogen-oxygen booster rocket (designed for the sole purpose of injecting the mission spacecraft into a trans-Mars trajectory) into the assembly orbit, and docking with the mission spacecraft

239. departure for Mars (with undocking of the booster rocket after its work is finished) at the most optimal date such that the escape velocity from near-Earth orbit is 3.7-4.0 km/s

240. insertion into a severely elongated elliptical Mars satellite orbit with virtually no fuel expense, as a result of braking of the spacecraft in the Martian atmosphere (during the motion in the atmosphere, the spacecraft must be protected from heat by a heat-protection shield)

241. separation of the mission module, its descent, operations on the surface, return of the module to orbit, rendezvous and docking with the orbiter, transfer of the mission module crew to the orbiter, separation of the mission module

242. injection of the orbiter from Mars satellite orbit into a trans-Earth trajectory with the sustainer engine of the orbiter's consolidated propulsion system

243. upon approach to Earth, transfer of crew to reentry vehicle, reentry at escape velocity, and touchdown.

244. The following figures can give us something of an idea of the overall size of the complex: with the total mass of the orbiter and the mission module and their propulsion systems and fuel at around

120 tons, the mass of the complex can be around 300 tons.

245. If the mission crew that lands on Mars consists of four individuals, then the total number of crew members for the Mars mission must be at least six.

246. The orbiter's onboard systems and computers must support in-flight operations such as control and navigation and communications with Earth, the mission module, and the Mars rover (via the orbiter).

247. Because of the need to minimize the mass of the spacecraft and because of the long duration of the flight, a closed-loop oxygen-and-water system will have to be used for life support.

248. The long flight of the mission far from Earth, with no possibility of giving any direct assistance to the cosmonauts, raises the question of whether the mission should consist of several spacecraft, who could provide such assistance to one another and, at the same time, avoid duplicating programs of operations.

249. A Base in Geostationary Orbit

250. A base in geostationary orbit could be used for servicing unmanned geostationary platforms, communications and television-relay satellites, and weather satellites that are in geostationary orbit; for observing the Earth's surface in the interests of the environmental monitoring and natural resources studies; for weather observations and astrophysical research; and for the construction of solar electric power plants.

251. The creation of a base in geostationary orbit does not appear today to be an essential task, but the development of communications and television-relay systems and the appearance of multipurpose platforms in geostationary orbit could lead to the conclusion in the future that a base in geostationary orbit is needed. The rest (communications, television, radio telescopes, etc.) represents incidental goals: if a base were to be created, then it would be logical to use it for other purposes, too.

252. The base could include an orbital unit; an external platform; a fueling station; and an orbital transport vehicle for carrying cosmonauts and cargo to vehicles and platforms being serviced.

253. In addition, the base could also include a manned transport spacecraft (for bringing crews to and from the base) and multipurpose cargo transport spacecraft (for delivering cargoes from low orbit to the base).

254. Based on a cost of $5,000/kg to put a payload into low orbit, using today's expendable orbital-injection systems would put the cost of sending a spacecraft weighing approximately seven tons (which includes the mass of the propulsion system and fuel needed for a return to Earth) to the base at around $250-350 million, depending on the launch vehicle used, the orbital plane of injection to the intermediate orbit, and the components used in the rocket stage for transferring the spacecraft from intermediate orbit to geostationary orbit. That's a lot. So we need to aim for as small a crew as possible on the station and for a rather long tour of duty. We can tentatively expect a base crew of three cosmonauts who serve a tour of duty of one year.

255. A base in geostationary orbit could be configured as a unitized structure, like the Mir station and the Freedom station project, or as a cloud-station, and it would consist of individual modules: an orbital unit with a platform (making up the main module) and a fueling station. In a cloud-station version, the fueling station would drift at a distance of 10-50 km away from the main module.

256. The orbital unit would have to have at least three docking ports-one for a manned spacecraft, a second for a cargo spacecraft, and the third for a backup spacecraft. All the inside facilities could easily be fitted in a space of 150-200 cu meters (a cylinder about 4 m across and 12-15 m long).

257. The inside gear for control and communications would include onboard computers; gyroscopic sensors and accelerometers; the radar receivers and responders used when spacecraft rendezvous with the orbital unit; gear for communications with Earth (direct and through relay satellites), with the transport vehicle, with cosmonauts doing EVAs, with the radio telescope, and with the fueling station; gear for processing telemetry; consoles; manual controls; instrument panels; displays; screens for displaying incoming information; and television gear.

258. In light of the cost of cargo deliveries, we would rely on a system that is completely closed-loop for water and oxygen and that uses for its functioning expendable materials in the form of equipment components that are replaceable in the process of operation. Dehydrated food, plus underwear and clothing, would be delivered by cargo spacecraft. The mass of those materials would be on the order of two-three tons a year in the context of an expected total freight traffic volume to the base of about 15-20 tons a year (remember that the freight traffic volume to the Mir station is 10-15 tons a year). Most of the cargo would consist of things like equipment for regular operations, instruments and assemblies needing

replacement, new scientific gear, and fuel.

259. On the outside of the orbital unit would be the platform, the propulsion system, the solar panels, the temperature-regulation system radiator, the optical sensors for the attitude control system of the orbital unit and the solar panels, antennas, and the powered gyroscopes of the attitude control system. Powered gyroscopes are used because, on the one hand, the orbital unit's communication antennas are always pointed toward Earth (i.e., in practical terms, attitude needs to be merely maintained) and because, on the other, an attitude control system that uses no fuel is needed (for the same efficiency considerations associated with expendable materials delivered from Earth). The location of the powered gyroscopes outside the pressurized spaces stems not only from the fact that the flywheels must rotate in a vacuum (in order to avoid windage losses), but also-and this is the main reason-from the consideration that a noise source be removed from the pressurized spaces.

260. The platform is a trusswork structure that supports the directional communication and relay antennas and the optical instruments that are operating in different spectral ranges and are used for observing the Earth's surface and the atmosphere.

261. The propulsion system is needed for placing the based in the desired region in geostationary orbit and for moving it to another region if the need arises. In addition, it can be used for keeping a cloud-base from ''racing apart'' in the event that the system for maintaining a given position relative to the main module goes out of order. Accordingly, the propulsion system includes a vernier engine, thrusters for control and coordinate shifts of the base with fuel, fuel-tank pressurization tanks, and pneumohydraulic valves. As fuel components, a gas such as dimethylhydrazine-nitrogen tetroxide would, of course, be used.

262. In a cloud-base, the fueling station would be an independent, unmanned space vehicle. For that reason, it would have to have a complete set of servo systems to support its existence: attitude control and stabilization systems (including a radar for rangefinding and measuring the radial velocity relative to the main module of the base, plus powered gyroscopes as controlling organs); a communications system; a temperature-regulation system; a power-supply system; life-support systems that are switched on when cosmonauts visit the fueling station; and a propulsion system.

263. The vehicle for making trips between the service facilities of the base would be an orbital craft capable of both manned and unmanned operation. In the unmanned mode, the craft could be used for simple service operations-such as fueling operations. For operations

of greater complexity that are associated with the replacement or repair of instruments and equipment, a crew would be sent on the craft. Since the service craft has no reentry capsule, it would consist of gear for control and communications, a power-supply unit based on solar panels, temperature-regulation and life-support systems, a propulsion system with a sustainer engine and steering engines, and a docking assembly. In addition, it must have systems for fueling the vehicle it is servicing: fuel-component tanks, pressurization tanks, a compressor (for pumping the pressurization gas out of the tanks of the propulsion system being fueled into its pressurization tanks), and automatic pneumohydraulic equipment. Naturally, the vehicles that are ''clients'' of the base in geostationary orbit will have to have standardized fuel components and pneumohydraulic systems for their propulsion systems (if only for fueling and safety), as well as docking assemblies.

264. The manned transport spacecraft can consist of three components: the reentry vehicle, the equipment section with a retropropulsion system, and a booster-rocket stage.

265. The reentry vehicle would hold the crew, equipment needed for the return leg to Earth, and the control gear and organs needed by the crew during the flight. The reentry vehicle has a heat shield.

266. The equipment section hold the following: control and communications gear; electric power-supply and temperature-regulation systems; life-support system backups; and the retropropulsion system. The retropropulsion system is designed to issue a braking impulse that ensures transfer from geostationary orbit to an elliptial orbit for return to Earth (during reentry in the equatorial plane, the required change in velocity is about 1.5 km/s); to adjust the trajectory of motion; and to effect control of attitude and coordinate shifts during rendezvous and docking. Since the propulsion system must remain ready for operation a long time (the manned spacecraft is expected to remain ''on duty'' as part of the base for the entire time that the crew it delivered remains on the base), it quite naturally uses high-boiling-point, hypergolic components.

267. The booster-rocket stage must lift the spacecraft from a low, near-Earth orbit to an elliptical transfer orbit (when operating in the equatorial plane, the required increase in velocity is about 2.5 km/s), and then, at its apogee, it must insert the spacecraft into a geostationary orbit (in the equatorial plane, the required increase in velocity this time is about 1.5 km/s). Four kilometers a second represents immense power needs. For that reason, it seems sensible to use oxygen and hydrogen as components in the booster-rocket stage. For a version so efficient, in terms of power, we can estimate the departure mass of that craft in low, near-Earth orbit to be on the

order of 50 tons. If we assume the cost of manufacturing the craft to be around $50 million and the cost of placing a payload into orbit to be $5,000/kg (half as expensive as putting a payload in orbit from the Shuttle), then for an expendable spacecraft we get a figure of around $300 million in expense for each crew change on a base in geostationary orbit.

268. Could we cut the costs of a crew change by developing and using a reusable manned transport spacecraft for the flights from the low intermediate orbit to the geostationary orbit and back?

269. Such a spacecraft could be seen as consisting of the crew flight deck, the equipment section with the retropropulsion system (which operates on high-boiling-point components), a booster-rocket stage that burns oxygen and hydrogen, and an aerodynamic shield that plays the simultaneous role of speed brake and heat shield.

270. Such a reusable spacecraft, without any recovery capsule, could operate in the following profile:

271. the retropropulsion system of a reusable spacecraft that is docked with a low-orbit servicing station is fueled with high-boiling-point propellant components

272. the next shift of cosmonauts lifts off from Earth in a transport spacecraft that travels between Earth and the low-orbit servicing station and that performs a rendezvous and docking with the station

273. the reusable spacecraft is fueled with liquid oxygen and liquid hydrogen, and the cosmonauts transfer to the reusable spacecraft

274. the reusable spacecraft separates from the servicing station, the engine of its booster stage is switched on, and it transfers to an elliptical orbit of flight for the geostationary orbit

275. at the apogee of the elliptical orbit, the engine of the booster stage cuts-in again, and the spacecraft transfers to geostationary orbit near the base

276. the spacecraft performs a rendezvous and docking with the orbital unit of the base by using its retropropulsion system

277. the crew transfers to the orbital unit of the base and begins its work.

278. When the crew finishes its tour of duty six months or a year later, it transfers to the reusable spacecraft, which separates from

the orbital unit of the base. The retrorocket is switched on, and the spacecraft is inserted into an elliptical orbit of descent.

279. Then the following happens:

280. the elliptical orbit is corrected so that the reusable spacecraft enters the necessary altitude corridor for atmospheric braking

281. the spacecraft makes reentry, and its control system controls its motion in the atmosphere via the aerodynamic lift of the speed brake in such a way that after braking and reentry, the apogee of the result orbit is roughly equal to the altitude of the orbit of the servicing station

282. when the spacecraft approaches the apogee of the resultant orbit, the propulsion system is switched on, and the perigee of the orbit of the spacecraft is raised to the altitude of the orbit of the servicing station

283. the spacecraft makes a rendezvous and docking with the servicing station

284. the crew transfers to the transport spacecraft that travels between Earth and that orbit, and the reusable spacecraft is readied at the servicing station for the next trip.

285. If we assume that same cost of delivering fuel to the orbital station ($5,000/kg), then the transfer to the reusable spacecraft could cut the costs for a crew change on the geostationary base by roughly half. But we must still consider the expenses incurred by the flight of the manned transport craft that travels between Earth and orbit and the costs of operating the low-orbit servicing station, which will be placed among the costs of operating the reusable spacecraft. So the gain may turn out to be not so substantial.

286. Nevertheless, the future is probably still with reusable systems. We need to go with them. A substantial cut in transportation costs, however, can be achieved only through consistent use of the principle of reusability and only through the creation of a truly efficient reusable transport system that can deliver cargoes to low, near-Earth orbit at a cost of around $100/kg.

287. As already mentioned, around 20 tons of freight will have to be delivered to a base in geostationary orbit every year. Hauling up that much with expendable cargo craft would cost roughly $500 million (assuming operations are in the plane of the equator). For that reason, we need to analyze the advisability of developing a reusable

cargo spacecraft.

288. Such a craft would take the form of a reusable tow craft with electric engines that receive the electrical energy for their operation from solar panels. With a tow craft mass of about 30 tons, and about 10-12 tons of that being fuel, the tow craft could deliver 10 tons of cargo to a base in geostationary orbit, i.e., it would use about a kilogram of its fuel for each kilogram of payload. Thus, the delivery of 20 tons of cargo to a base in geostationary orbit would cost $200-250 million (even if the cost of putting the cargo into low, near-Earth orbit were assumed to be $5,000/kg). Such a tow craft, of course, would have a big drawback: the slowness of the delivery of cargo, since its flight from low orbit to geostationary orbit would take several months.

289. For that very reason, and because the craft would be long in the radiation belts, spacecraft with electric engines will hardly be used to delivery crews to bases in geostationary orbit (a crew would have to sit in the small space of a radiation shelter for two months during the flight).

290. Space Settlements

291. The Earth is overpopulated. The ecological problems that have risen up before mankind at the end of our century are the result of not only the irresponsible waste of natural resources and imprudent industrial and agricultural practices, but also the fact that there are already too many people on Earth. Maybe that's why the old idea of resettling people in space is again beginning to attract attention. Since the 1970s, suggestions have been appearing on the creation of space settlements.

292. One of the most brilliant projects belongs to J. O'Haley. He and a group of enthusiasts have developed and proposed several types of space settlements that differ in size and whose populations range from 10,000 to 20 million. In the latter case, the settlement consists of two parallel cylinders joined by a frame; each cylinder is 6.4 km across and 12 km long. The cylinders are rotated about their axes at a rate of 0.53 rpm, which produces a centrifugal acceleration on the inner surface, which is inhabited by the people of the settlement, and that acceleration is equal to the normal acceleration of the force of gravity on the Earth's surface.

293. The cylinders rotate in opposite directions to compensate for their angular momentum, so it won't interfere with the orientation of the settlement. The axes of the cylinders point to the Sun. Part of the wall (roughly half) is transparent, and offset, cylindrical mirrors direct the light from the Sun into the cylinders. The length

of the mirrors is equal to the length of the cylinder, and the width corresponds to the width of ''windows.'' Energy is supplied to the population from thermoelectric power plants that get their energy from the Sun via two parabolic mirrors on the ends of the cylinders opposite the Sun. The ends of the cylinders on the Sun side have docking positions for spacecraft.

294. Inside the cylinders is a normal terrestrial atmosphere. Main transportation arteries are laid out on the inner surface of the cylinders, and on that surface is also housing, factories, public buildings, stores, etc. All that is, as it were, beneath one hilly roof (the roof is toward the axis of the cylinder-''up'' for the inhabitants is toward the axis of the cylinder). The roof is covered with soil, and growing on it are trees and grass, on which agricultural operations are performed; strolling lanes have also been laid out, and there are ponds and lakes. In a word, a terrestrial landscape is reproduced above the living and industrial facilities. The settlement has a closed-loop life cycle that uses biological as well as chemical-mechanical methods. Construction materials, raw materials, nitrogen, carbon, and hydrogen are brought in from Earth, the Moon, the asteroids, etc. The population density is on the order of 30,000 people per square kilometer, which is roughly three times higher than the population density in Moscow. Thus, each cylinder is a city like New York or Moscow, with a population of 10 million, but where virtually all the housing and all the industrial buildings have been moved so they are under the ground.

295. The mass of a settlement is around 10-15 billion tons, which immediately brings up the question, Where do you get such a huge amount of construction materials? Those to whom the idea belongs suggest getting the materials from the Moon. That suggestion is tied to some extent to the location of the settlement. They suggest that it be located at the fourth or fifth Lagrangian point in the Earth-Moon system, each of which is located on the Moon's orbit equidistant from the Earth and the Moon. Lagrange showed that a body located at one of those points will maintain a stable position in the Earth-Moon system. That feature of the Lagrangian points could, according to the thinking of O'Haley and his group, make delivery of materials from the Moon to the construction site somewhat easier.

296. Extraction, delivery, and processing of the materials is described by the group in the following manner. A highly automated mining and ore-dressing industry is set up on the Moon. Ore-bearing rock is processed to the needed condition and then poured into standard ''buckets,'' which go to an electromagnetic catapult. Since there is no atmosphere on the Moon, all the acceleration takes place at the Moon's surface. A linear synchronous electric motor (which is the catapult) accelerates the buckets containing the rock to the

proper velocity, and then the deceleration mode is switched on. The buckets are open in the direction of motion, and for that reason, when the motor is switched to a deceleration mode, the prepared rock flies out in the direction of the acceleration. The direction and speed are chosen such that the rock ''flies'' to the second Lagrangian point (which is located on a line between the Earth and the Moon, opposite the Earth). There the rock is collected by ''interceptors,'' and on freighter spacecraft that are powered by electric engines it is taken to the construction site. Back on the Moon, the motor slows the buckets to virtually zero velocity, and they are dispatched for the next load, and the next cycle of acceleration begins.

297. Based on a 15-year construction period, nearly 1 billion tons of processed rock a year (30 tons a second in continuous ''tossing'') must be sent from the Moon. And if we want to stabilize the Earth's population with a continuous emigration of the excess population to space, then an excess of 50 million people a year would require that nearly 40 billion tons of rock a year (that's 1,300 tons a second!) be dispatched from the Moon. But that is considerably more than everything that is being mined right now on Earth.

298. Warehouses for raw materials, semifinished products, and finished products would have to be built at the construction site, in the vacuum, as would plants for things like ore dressing and metallurgy. The productivity of that industrial country in space (the whole operation is get ''housing'' up in time for the growing humanity) would have to be on the order of 30-40 billion tons of product a year: that is roughly equivalent to what the industry of the entire Earth is capable of processing and producing.

299. Another project under the name of the ''Stanford Torus'' (it was developed at Stanford University, in the United States) proposes building space settlements in the shape of tori 1.6 km across, with a cross-section diameter of about 150 m. In practical terms, such a settlement, designed for 10,000 people, is a densely developed city in the form of one closed street with a solid wall of homes and buildings on each side.

300. The torus rotates around its axis of symmetry to produce gravity for its inhabitants. A mirror hovering over the torus (with a diameter roughly equal to the diameter of the torus) reflects the Sun's rays onto a circular mirror that is rotating along with the torus, and that mirror directs the light through round ''windows'' into the torus.

301. Along the axis of the torus are equipment, docking positions, and industry. The air pressure in the torus is 0.5 atm, with a

partial oxygen pressure that is normal for Earth.

302. Because of the smaller dimensions in terms of the ''height'' and ''width'' of the habitable space, the mass of the structure of the settlement in this project is roughly an order of magnitude smaller, but then the amount of space per person is also an order of magnitude smaller. But even in this version, it's easy to see that the creation of space settlements cannot be a means of solving the problem of the overpopulation of the Earth. In theory, one could imagine such grandiose operations as being feasible if mankind were to somehow acquire enough robot-entities that were specially created for living and working in space, were absolutely efficient (and always had a strong desire to work), could themselves design and build whatever they wanted and wherever (like genies), and still would take orders from poeple and would obediently carry those orders out.

303. But even if such settlements were built, would people want to live there? Live your whole life in a can. So what if it's a very big can, 150 meters in diameter! That's something for the psychologists. We might be able to think up some ''tin'' idea, but for Pete's sake it sure wouldn't hold up forever.

304. Space settlements for tourists along the lines of a Las Vegas in space-now that's something one might imagine, and such settlements might just spring up.

305. So it's unlikely that space settlements would save us from ecological disaster or overpopulation of the Earth. Mankind must someday grow up, and stop reveling in its fertility. Not by strong-arm methods or restrictive legislation, but by understanding the current circumstance must mankind as a whole and each individual separately arrive at the clear solution: we must put a stop to the growth of the human population. A natural ethical norm must be affirmed in people's awareness-that no woman should have more than two children. If all people were to adhere to that norm, the population growth would cease, and we would have a real chance of averting ecological disaster on Earth.

306. Flight to the Stars

307. Almost since the days when space program was taking its very first steps, it has been clear that anything within the solar system is reachable by the space vehicles or spacecraft that could be developed with the level of technology available and that, consequently, even if humans couldn't land on all its planets, they could at least make it to them. But at the same time, it has also become clear that here at home, in the solar system, we probably

won't find anything unusual. It's unlikely that, with the data we produce on our trips about our solar system, we will be able to move very far forward in our understanding of the physical picture of the world in which we live.

308. That means we need to look to the stars, and starships. What kinds of problems need to be solved before star missions can become a reality?

309. The first problem is time. Even if we could build a starship that could fly at a speed close to the speed of light (say, at a speed on the order of 70 percent the speed of light), travel in our galaxy would take thousands or even tens of thousands of years, because the diameter of the galaxy is nearly 100,000 light years.

310. At the end of a journey, what would be left even of cosmonauts who had been ''frozen''? What would be left of embryos? And do we have a right to decide the fate of people who haven't even been born yet? And even if we could solve that problem, the travelers would come back to a world totally foreign to them. A flight to the stars wouldn't be merely a trip, it would be a flight to another life. For those around you, your relatives and friends, it would be something akin to your suicide.

311. The second problem involves dangerous streams of gas and dust. Interstellar space is not empty. Remnants of gas and dust, streams of particles, are everywhere. For a starship traveling at a speed close to the speed of light, those gas and dust remnants create a high-energy stream that would act upon the ship and against which there would be virtually no protection.

312. That stream would result in the vaporization of any protective shield and in unacceptably high radiation dose levels.

313. The third problem involves power needs. If a ship's rocket engine were to use the most efficient thermonuclear reaction and the ship were to have the ideal design, a roundtrip at a speed of near the speed of light would require that the ratio of initial mass to final mass be no worse than 10<sup>30<reset>, which is unrealistic.

314. And as for the creation of a photon engine for the starship, which would be based on the use of annihiliation of matter, certain problems are evident, but their solutions are not. Nevertheless, let's try to imagine a galactic, photon-powered ship capable of flying at a speed rather near the speed of light, which would remove the problem of time. The time itself that it would take for cosmonauts to fly roundtrip on a journey covering a distance equal to about half the diameter of our galaxy- assuming an optimal timetable

for the flight (continuous acceleration, and then continuous deceleration)-would be 42 years (by the ship's clock). By the clock on Earth, 100,000 years would pass.

315. Let's assume that we managed to produce an ideal process in a photon engine and create an ideal design for tanks with zero mass (that's impossible, of course, but that only means that, in fact, the results would be considerably worse), and let's try to analyze certain parameters of such an ideal craft.

316. The initial-to-final-mass ratio would be 7 x 10<sup>18<reset>. That means that if the mass for the living quarters and the working areas and equipment (i.e., everything that the spacecraft carries) were a total of 100 tons, then the departure mass would be 10<sup>21<reset> tons. That's more than the mass of the Moon. Half of that mass would be antimatter.

317. In order to ensure acceleration equal to g, the engine would have to develop a thrust equal to 10<sup>24<reset> kgf. To produce that kind of thrust in the focus of the mirror of a photon engine, there would have to be an emission source (whose operation is based on the annihilation reaction) of around 10<sup>40<reset> erg/s. Remember that the emissive power of our Sun is on the order of 4 x 10<sup>33<reset> erg/s. Thus, in the focus of the mirror of the photon engine, we would need to ignite millions of Suns!

318. The parameters of a photon-powered ship would be considerably better is it were possible to build a hypothetical ship with a ramjet photon engine that carried only antimatter. But the analysis would show there, too, the need to achieve impossible results-in the focus of the mirror of even that engine, we would need to ignite hundreds of Suns. And with all that, there still remain the problems of time and protection from streams of gas and dust.

319. Based on today's notions of the world, we are left with the impression that we cannot solve the problem of transporting material bodies galactic distances at speeds close to the speed of light. Apparently, there's no point in charging through space and time in a mechanical structure.

320. We need to find a means of interstellar travel that does not involve the need to transport a material body. In doing so, we approach an idea long used in science fiction (which need not be embarrassing, because profound ideas have more than once been expressed in science fiction literature) about the travel of intelligent beings in the form of information packages.

321. Electromagnetic waves propagate throughout the entire

observable Universe with virtually no loss. And that may be the key to interstellar flights. If we want to stay away from mysticism, we must acknowledge that the person of today's ''organic'' man cannot be separated from his body. But we could imagine a specially engineered individual whose person could be separated from the body in a manner somewhat similar the software that can be removed from the structure of today's computers.

322. If an information package that is a complete description of his person, his individuality, could be copied from his fields of foreground operations and memories, then that package could also be sent by radiolink to a receiving station and copied into a standard material carrier (or a carrier chosen by price, or...) in which the traveler could live, act, and satisfy his own curiosity.

323. During the transmission of that package of information, the individual would not be alive. In order for him to be alive, his person-his package of information-would have to be in a material carrier. His person, or, if you will, his spirit, could exist only on material fields of operation and memory.

324. Such a means of handling the problem of flying to the stars could be behind the plots not only of modern science fiction, but also of ancient worlds, fairy tales, and legends about ascensions into the heavens and condemnations to hell, about flying saucers and worlds where people appear and then disappear, about transmigration of the soul. It could be the resolution of philosophical arguments and discussions about the essence of man, the frailty of this corporeal shell, and the essence of being. What is man? What is truth?

325. It is interesting what outstanding philosophers from different times have, through logical analysis (not based on knowledge), come to the thoroughly modern notion of the relationship between essence and the human body. The life of man is the life of his soul; it is the thought that beats in feebleness about oneself (''Who am I?'') and about the world outside oneself and inside; it is the esthetic enjoyment of beauty and the rejection of the primitive and the untruth; it is the freedom of thought and analysis. We are here, we are living, and we are capable of reflecting on, evaluating, and reprocessing information and generating it. The rest of me, my body, is for service.

326. The brain is a field of mathematical operations on symbols, numbers, concepts, laws, and algorithms. Those operations ensure the integration of incoming information and its analysis. The algorithms that have come about in man for processing, analyzing, and evaluating information determine his esthetics and self-image, and they

determined his sense of his own existence. Of course, those operations are performed according to laws that are specific to a given individual. Those laws form in the brain of an individual gradually (as a result of his experience in gaining and reprocessing information and his experience in his own activity and the evaluation of it), and they are recorded on the fields of mathematical operations and the memory units of his brain. Over the course of his life, those laws may be improved, they may be changed (just as man changes over the course of his life), and they may deteriorate. Recorded on a material carrier, they become, as it were, material. But the operations themselves, our thoughts, our experiences-they're not something that is tangible. Throughout all time, man has tried to materialize those ''intangibles'' in the form of sounds, words, stories, manuscripts, and books. But they have always been only shadows, weak reflections of those ''intangibles.''

327. The overwhelming majority of people-almost all and almost always-have not made the distinction between their ''I'' and their ''body.'' And it is the body that they have always tried to make things a little better for. And in general, that's necessary: without nutrition, the brain dies, the field of operations decomposes, the person disappears. At the same time, in a healthy body, the ''computer'' works with fewer breakdowns and with greater speed (because of simultaneous operations and because of better algorithms in general), and the interior is greatly resistant to external threats and complications. And the most important thing is that a healthy body means clear thinking.

328. Maybe that's why the striving to makes things a little better for the body from generation to generation has remained the main driving force of the human race. It has also resulted in predatory campaigns, the creation of new technologies, and the striving for a better organized life for society (including by means of ''Let's rob from the rich,'' which is camouflaged by ''Down with exploitation''). Homes, cars, airplanes, gas and electricity, and computers were all born out of that striving. A striving to make things a little better for the body has been and remains the prime mover in people's lives.

329. But in fact, all that is secondary. Our ''I,'' our individuality, our essence, our being-that's not our material shell. There's nothing that contradicts our perception of the world in the thought that it is fundamentally possible to separate individuality and its material carrier.

330. For that reason, from an engineering standpoint, it is possible to engineer an individual whose spirit could be ''separated'' from his body, and a world could be engineered in which the individual could move almost instantaneously (in the the solar system, for

example) from one planet to another.

331. Would it be okay to create such a being? Do we have the right to do that? What incentives could we inculcate in him? It is those very questions that describe the main problem. Things are different with us, probably the product of organic evolution. The instinct for survical, for continuing the species, is deeply seated in us. A species that doesn't have that instinct or in whom it's not well developed does not survive in natural selection. But never mind natural selection! When because of age, health, or living conditions that instinct dies, the individual loses the will to live. But what kind of incentive to live could we give to our creation? Curiosity? The desire to be useful to those who created his body (which is perishable and replaceable) and who raised his person and his soul? The desire to be involved in studies of the world, in ultradistant travels, in the creation of transceiver stations for travels, in the construction of space bases near stars?

332. Are those incentives persuasive? Where would such an individual get fondness and love for those around him? How would we raise him so that he wouldn't turn out to be a monster with absurd, senseless aspirations for power or for the opportunity to give orders? How would we raise him to learn from and be like his benefactor? Or just the opposite. How would we raise him so that he wouldn't turn out to be an infantile, passive being who is apathetic about the world, about those around him, and about himself?

333. And finally, there would be enormous technical problems. How do we think? How are the stereotypes of our responses, our behavior, our evaluations created? How does our individuality come about? The algorithms of our perception of the world around us, of our analysis, and of our thinking are probably created anew in every human and, to a certain extent, differently. Their nature is determined by family, friends, and enemies; by school and the structure of society; by the joys and pains and successes of childhood. A society of slaves raises slaves, a society of freemen, freemen. From that standpoint, it's very dangerous to standardize methods of education. That's the most terrible thing we can do for our future. Mankind can be strong only when there are differences, diversity, and individuality. Of course, there must be certain common bases: love those around you, don't steal, don't kill, don't covet. But to prepare man fit a mold is to prepare our own demise.

334. Without having sorted all those things out, how can we set about creating artificial intelligence?

335. But the notion of it has already entered our consciousness. Perhaps the most popular problem among the most curious and

enterprising among us is to create artificial intelligence. We have to think about it, because it's going to happen.

336. And difficulties that are more comprehensible would come up. If we were to transmit an individual over galactic distances, we would have to create antennas whose dimensions measured in kilometers, plus transmitters with powers on the order of a 100 million kW. At the same time, if we were to effect such galactic transfers, we would have to create receiving and transmitting stations (in the radio range, for example), use unmanned space vehicles, for example, to put them at possible destination points (as a rule, not far from some star, so as to ensure that the transceiving stations would have a supply of energy). We could transport the transceiving stations, but we could only take the technology and a minimum set of instruments and robots for the manufacture of those stations at the destination.

337. The speeds of space vehicles that are now flying in the solar system are in the tens of kilometers a second. It's possible for us to achieve speeds in the hundreds or even thousands of kilometers per second. But that means that it would take millions or even hundreds of millions of years to ''transport'' the stations about the galaxy. Transporting stations at such speeds even to the closest stars, which are tens of light years away from us, would take thousands or tens of thousands of years. In that length of time, the interest in the project itself might be lost.

338. One could imagine another means of star traveling: establish communications with other civilizations; transmit to them the information on the construction of transceiving stations suitable for receiving ''our'' people; transmit the information needed for manufacturing a material carrier of ''our'' individual; transmit the information package with ''our'' traveler; and set up an exchange of information with them.

339. Reflecting on stellar flights enables us to single out several promising areas of work that we would be wise to pursue in the coming decades. They include the following: create ever larger radio telescopes with outputs measuring in the kilometers; develop space robots and designs and ideologies for space ''beacons''; study the possibility of creating artificial intelligence; and search for channels of communications to other civilizations in the solar system.

340. Those areas are well in keeping with the modern needs of man. Work on artificial intelligence is associated with solving the problem of creating sufficiently efficient robots to replace people in dangerous production work and help us in our exploration of water areas and the underwater world and in construction. The creation of

space robots is a an idea whose time has come. Robots would be more effective in working in open space than is men in space suits. And operations in open space will probably expand in the coming decades.

341. The construction of large radio telescopes will enable us to make more efficient studies of the Universe.

342. What Needs to Be Done?

343. Without any pretense to making an exhaustive list of the tasks facing space operations in the coming decades, I will attempt to describe the goals on which, in my opinion, it makes sense to focus our efforts:

344. 1. Low-orbit systems of standardized satellites for environmental monitoring, studies of natural resources, and weather observations, with computerized ground centers for processing the information and a computerized system for delivering the results to subscribers.

345. 2. Orbital cloud-stations as bases for experimental and construction work.

346. 3. Orbiting factories for the production of ultrapure materials and biological preparations and for performing other production processes that would be profitably or advisedly done in orbit.

347. 4. Unmanned space vehicles in an international satellite system for observing and monitoring land, sea, and ocean surfaces, air transport, and underwater activity, with a system for distribution the information to subscribers.

348. 5. Systems of radio telescopes placed in near-Earth and circumsolar orbits and operating in a single radio interferometry configuration.

349. 6. Orbital astrophysical observatories working in various spectral ranges.

350. 7. Unmanned vehicles for bringing back Martian soil and air samples (if, as a result of those operations, it turns out to be necessary to perform a manned mission to Mars, then the appropriate manned mission systems will have to be developed and built).

351. 8. Reusable transport spacecraft that are cheap (cost of delivering payload to orbit in the hundreds of dollars per kilogram) for transport operations between Earth and orbit.

352. 9. Cheap, reusable transport spacecraft for transport operations between low orbit and geostationary orbit.

353. 10. Space robots for operations in open space in Earth satellite orbits.

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