Selection of Concepts for First Manned Missions to Mars

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INTRODUCTION

This presentation states the Russian concept for the first manned missions to Mars and main reasons supporting the various solutions based on the concept. The concept is expected to maximize the use of the verified Russian technologies and facilities, including those employed in the Russian programs for orbital stations.

A major concern in selecting the Martian mission concept is assuring crew safety, to the extent achievable during missions to orbital stations. Although the program is ambitious, this requirement appears fundamental. Crew safety will be achieved through proper technical solutions as well as ground and flight tests.

1.0.0. Mission goals

Mars is a unique planet on which to investigate evolution of the solar system planets, predict evolution of the Earth, and explain the origin of life. The central idea behind exploration of Mars, however, is that Mars is the only planet tenable for future human settlement. Exploring the possibility of Mars settlement as a means to save the Earth's civilizations is likely to be the most important goal of a manned Martian mission. Various global catastrophes on Earth pose real threats, so deferring the lengthy process of extraterrestrial exploration would be unreasonable: «Eggs should not be left in one basket». (Fig. 1).

2.0.0. Approach to optimized mission selection, selection criteria, and conceptual solutions

The solutions to mission aspect and spacecraft configuration problems shall be based on the following criteria:

- Crew safety
- Program cost
- Development period
- Project failure risk
- Anticipated mission results
- The extent to which technical solutions for the mission could be applied to other programs

Plans for the first mission to Mars should not be valid for one occasion only, and the mission should not be considered as an end in itself. The technologies developed while preparing for the mission can and should be used to solve other important problems faced by humankind (e.g., ground power engineering and ecology, exploration of the Moon and the other planets of our solar system, and certainly further Mars exploration).

Among a vast number of technical solutions to be found in the process of developing a Martian exploration plan is a class of solutions that will have an influence on the configuration of all other parts of the mission Complex [spacecraft system design]. It is conventional to identify such solutions as “conceptual” (i.e., defining the mission concept). Design work should begin with such steps as selection of a propulsion unit for the interplanetary mission, the mission scenario, a launch vehicle to deliver the Complex elements to orbit, and the appropriate crew size.

3.0.0. General characteristics of the Russian concept for the Martian mission

3.1.0. Evolution of the RSC Energia concept and project for the manned mission to Mars

RSC Energia [a major aerospace company in Russia] is a leader in manned space missions and has worked for many years on projects involving spacecraft sent to Mars (Fig. 2). Beginning with the first project in 1960, it was decided to employ electric propulsion for the interplanetary mission, with a nuclear reactor as the propulsion unit. In 1969, the concept was refined. The nuclear reactor’s capacity was increased and the number of descent modules decreased to a single module. Launch vehicle H1 was designed to place the Martian Complex elements into orbit. In 1988, in response to progress in developing photovoltaic converters and transformable truss structures, the nuclear reactor was replaced with film solar arrays. The motivations behind this choice were that such a propulsion unit could be made of several independent modules and its reliability could achieve a level beyond that possible with engines of other types. Launch vehicle Energia was designed with these considerations in mind.

Over the years, the project has been modified, with improvements in and simplification of the solar array deployment technology. In addition, the vehicle design was modified to enable its delivery to low Earth orbit not only by launch vehicle Energia but also by other launch vehicles, including Proton (Fig. 2).

3.2.0. Strategy for first missions

In selecting the strategy for the first manned missions to Mars, it is necessary to first determine the basis of these missions. Should they begin with building an infrastructure on the Martian surface in the area that is deemed most attractive from a human exploration viewpoint, or should explorers have a variety of bases in different areas that have been explored by robotics, with all needed facilities and equipment delivered to the base for each expedition?

A properly equipped base built in a specified area of the Martian surface would provide the ability to adequately explore this area. Production facilities could be built there to make use of Mars' resources for life support systems (required by a prolonged human staying on the planet) and to produce propellants for travel to other locations on the planet. The manned expedition would fly to another area where a less-developed base is already deployed.

As an alternative, expeditions might first be sent to various areas. If a base is needed at any of them, infrastructure will be built for in-depth exploration of the area.

The first scenario pursues the following logic. Assuming a final goal of Mars settlement, missions must create conditions on Mars from the very beginning that allow for manned missions to Mars on a regular basis. Prolonged human activities should be made possible on the Martian surface, including the use of Martian resources and production of propellants for ascent modules. Use of Martian resources rather than those sent from Earth would reduce the cost of manned missions to Mars. Prolonged stays of crews on the Martian surface would make human exploration of Mars more cost-efficient by reducing the number of flights to the planet.

This scenario also has weak points. First, the program would require much more funding from the very outset, leading to the question: Is it reasonable to plan for Mars settlement from the beginning, even before the first manned mission to this planet? This scenario also links Martian exploration to a specific area of Mars. Exploration of other areas would require movement of crew and materials from the established base.

Because of concerns for crew safety in the first missions to another planet, mission success must be made independent of availability of Martian resources. Scenarios for the first manned missions will involve delivery from Earth of all necessary facilities and equipment for work and for the safe return of the crew to Earth. Is there any reason to anticipate the development of facilities to employ Martian resources before the mission?

The logic of the second scenario is based on gradual development of the Mars exploration program. It assumes that the first missions will occur without construction of bases for long-term human operations on the planet’s surface. This logic contemplates that further settlement of Mars will be deferred for some time.

This approach also has its weak points. The major point is that the organization of any manned mission to Mars will require considerable funding. We must ask whether the results from crew activities on the Mars surface during a relatively short period would make such a short-term mission or missions financially viable. (Fig. 3).

Analysis of all technical and general problems and risks of all types, for both scenarios, led to selection of the second approach: organization of the first missions to Mars without building a base on the planet’s surface for crew operations. The inexpedience of linking a landing site to the preliminary deployed base was the primary motivation behind this approach.

3.3.0. Conceptual solutions

3.3.1. Propulsion selection for the interplanetary mission

The choice of propulsion for the interplanetary flight is critical. The spacecraft configuration and the mission scenario depend strongly on this choice.

A large variety of propulsion units and their combinations could be employed for the Martian Complex flight in the interplanetary trajectory. The following major classes should be considered for the interplanetary flight: liquid-propellant, nuclear, or electric propulsion using solar or nuclear power. (Fig. 4).

Liquid-propellant engines are the most extensively tested, but their efficiency is rather low and the initial mass of the Martian vehicle will be quite large. These factors would increase project cost and the time needed to assemble the vehicle in the low Earth orbit. Despite the great worldwide experience in developing such propulsion, it appears highly problematic to design a multistage liquid-propellant interplanetary rocket with the required reliability. In addition, such a solution would not contribute to progress in other areas of space exploration.

Nuclear propulsion offers the significant advantage of reducing the initial mass of the Martian vehicle while bringing a number of complicated engineering problems associated with ground tests. Using this form of propulsion, just as for liquid-propellant engines, a problem is how to achieve the required reliability of the multistage rocket.

The advantages of electric propulsion for interplanetary missions has been shown even in the early phases of RSC Energia's work on the subject. Electric propulsion engines are regarded as the most efficient among those in existence. Their use offers high reliability and low cost of the mission.

Tugs using electric propulsion would give the ability to efficiently extend space exploration.

It is important to determine what power source shall be used for electric propulsion. Today, two options are considered feasible: a nuclear reactor and thin-film solar energy photovoltaic converters.

Reliability of the interplanetary mission is the main motivation behind the choice of electric propulsion; these engines are remarkable in their multiple redundancy. Electric propulsion using solar energy could be designed with a large number of completely independent modules, so that a failure of one or a few modules would have no impact on mission implementation and crew safety.

There is one more advantage offered by electric propulsion using solar energy. Current conceptions of human missions to Mars assume that the crew return will in a special capsule with Earth entry atmospheric acceleration. In this case, the Interplanetary Complex will fly by in the heliocentric orbit without Earth entry atmospheric acceleration. An ecologically safe propulsion unit with a high specific impulse gives the ability to brake the Complex in Earth's atmosphere to make it reusable. Reusability of the Interplanetary Complex is another dimension of quality and would affect total program costs.

3.3.2. Mission scenarios

The mechanics of flying in the orbits of Earth and Mars around the Sun have consequences for design of the flight trajectory for the vehicle with the crew aboard. Flying from one planet to another requires that their mutual positions be known, and these positions will be different for the mission from the Earth to Mars and for that of the return trip.

A period of holding in the Martian atmosphere therefore must be foreseen during the wait for a moment when the planets are suitably positioned for the return flight. The goal is to minimize propellant consumption and, consequently, the initial mass. The holding period is about 1.5 years. One problem to be solved is how to protect the crew against galactic radiation during such an extended period. It may be possible to bring the whole crew to the Martian surface (and below) to make use of the Martian soil as a protective shield against galactic radiation.

The support of crew operations on Mars for prolonged periods of time would considerably increase mission cost. In addition, this would complicate the mission scenario: The whole crew will leave the vehicle for 1.5 years, and procedures must be worked out for accommodation of living quarters below the Martian soil, as long-term residence on Mars would require. Those factors reduce the total probability of mission success, and the entire scenario has to be played during the first mission.

There is a way to return to Earth using a non-optimal trajectory to avoid the holding period. For that, additional propellant would be required, but that would be offset by lower requirements for life support products to sustain the crew.

Trajectories used in the given project have no holding period, and the total mission time is reduced to the maximum extent possible.

There are different scenarios for the Interplanetary Complex mission, including multivehicle scenarios. For example, a vehicle carrying the crew and an Ascent-Descent Vehicle could fly to the Mars orbit separately. All the multivehicle schemes complicate a scenario and, consequently, reduce crew safety. That is why a single-vehicle scenario has been accepted for this project, a scenario in which the vehicle carrying the crew and the Ascent-Descent Vehicle will be flown to the near-Mars orbit within a single Interplanetary Complex.

3.3.3. Launch vehicle selection

The Interplanetary Complex configuration strongly depends on the mass and dimensions of the payload of the launch vehicle delivering the Interplanetary Complex elements to the low Earth orbit. (Fig. 5).

Assuming that the launch mass of the Interplanetary Complex equals 500–600 tons, the acceptable range for the launch vehicle carrying capacity will be 50–200 tons. The higher the carrying capacity, the fewer launch vehicles required, but the risk of hardware loss in the event of a launch vehicle accident increases.

The required mass of the launch vehicle payload within the given limits has no strong motivation behind it. Choice of the launch vehicle carrying capacity will depend on the cost and feasibility of different launchers. Analysis must consider the overall program of space exploration. This analysis is rather complicated; its results are subjective and essentially uncertain because they depend on goals of space exploration as a whole.

To reduce the complexity of the decision, feasibility of the human Martian mission program was not associated with the development of a new launch vehicle—launchers available at the time, including Proton, must be employed. This constraint will determine the configuration of modules and elements of the Interplanetary Complex.

The employment of Proton and its derivatives seems to be not the best, but a possible option. If this option is selected, it would be required to undertake certain measures to ensure a high launch rate for these launchers.

3.3.4. Crew size definition

Many of the mission parameters and design choices for the Complex elements strongly depend on the crew size. The smaller the crew, the simpler solutions can be found for various technical problems such as spacecraft configuration and cost, recovery from different contingencies, and radiation protection. What is the minimum crew size?

Within the scenarios under consideration, an important step is when the crew must be split into two teams. One team will descend to the Martian surface, and the other will stay in the main part of the vehicle and carry out research from the near-Mars orbit. For various reasons, each team should contain more than one man.

These reasons include the purely psychological as well as the necessity for team members to provide mutual aid in different situations, including a sudden illness. The minimum team size is 2; therefore, the minimum expedition crew size is 4.

Considerations prompting the decision to increase the crew size beyond the minimum follow. The first consideration is that the Martian vehicle crew cannot count on outside help for a rather long period of time. Therefore, the crew should include engineers with a variety of specialties, medical doctors, and scientists in different disciplines.

A list of desired or necessary specialties for the crew members could be rather long. A reasonable method of matching a crew to such a list of desiderata is to find crew members with training in multiple desired fields. This way is expected to lead to the problem solution because of the large pool of candidates across the globe and the time available to train future cosmonauts.

The other argument for increasing crew size beyond the minimum is the enhanced capability of mutual aid. At present, there are no strong grounds to believe that a team size of 2 (total crew of 4) is insufficient to render mutual aid, especially because the crew will be split into teams only for rather short periods of time.

With all these considerations in mind, the crew of 4 is considered appropriate for this project. (Fig. 6)

3.4.0. Mission program

The Martian mission program is described below. The Interplanetary Mission Complex elements will be lofted into the near-Earth orbit. Assembly of the Complex will take several months; therefore, the crew responsible for assembly will be rotated, just as on orbital stations. After preflight testing, the Martian mission crew will be transported to the vehicle.

The first mission phase is reaching the interplanetary trajectory. Flying with a low thrust means that this phase will last for a long time. The vehicle will make numerous orbits of the Earth, picking up the velocity required for transition to the interplanetary trajectory.

For most of the interplanetary flight, the electric propulsion will be used for transition to the near-Mars orbit. Thereafter, the vehicle will start moving in a twisting spiral around Mars.

Once in the low circular orbit around Mars, part of the crew will move to the Ascent-Descent Vehicle. That vehicle will land on the Martian surface at a destination selected in advance.

Cosmonauts will explore the Martian surface for a period from 10 to 20 days, then ascend to return to the vehicle. Again using the twisting spiral trajectory, the vehicle will pick up enough velocity to fly back to Earth.

In the Earth’s atmosphere, the Complex will enter the twisting spiral orbit from which it left for Mars. Here, necessary operations will be carried out to deliver propellants and components needed for the next flight to Mars. The mission to Mars and back will take about 2–2.5 years in total. (Fig. 7).

3.5.0. Martian Complex [Spacecraft System] Configuration

3.5.1. Complex elements

Given the mission program, the Interplanetary Complex should consist, at a minimum, of three parts: an Interplanetary Orbiter (IPO) where the crew would work throughout the mission, a propulsion unit to fly the vehicle along three trajectories, and an Ascent-Descent Vehicle (ADV) to deliver the crew to the Martian surface and ascend from it. (Fig. 8).

The planned Complex contains one more element—the Crew Return Vehicle (CRV). Taking into account that the entire Complex descends to the low Earth orbit, there is no definite necessity for this vehicle, especially because it will not be necessary to put the crew in quarantine in orbit after its return from Mars (unless signs of primitive life on Mars are found).

There are other reasons for including the Crew Return Vehicle in the Complex. Among those are that it will reduce the time the crew spends in flight in the Van Allen belt when returning from Mars and minimize stock of propellants needed to protect the crew against radiation. The vehicle would fly along the spiral trajectory to a low assembling orbit for 2–3 months, and the vehicle carrying the crew would descending to this orbit in only a few hours.

In addition, with such a vehicle available, it would be possible to reduce the amount of propellants used to brake the Complex in the Earth's atmosphere to counteract different off-nominal situations in flight. In this case, the Complex will fly by the Earth and lost. The crew will return to the low Earth orbit in the CRV.

The mass of the Complex elements is given in Fig. 9.

3.5.2. General requirements for the Complex configuration

The Complex is remarkable in that it contains high-power (15 MW) solar arrays with an area of about 150,000 m^2. In defining the Complex configuration, it is necessary to allow for the facts that the solar arrays must be permanently pointed toward the Sun and that the propulsion thrust vector has to change its orientation relative to the Sun's direction. Therefore, a joint with electric drives is needed between the solar array structure and the propulsion unit. Following analysis of different kinematics circuits, a configuration was accepted in which the solar arrays and the Interplanetary Orbiter constitute a single rigid structure that is pointed toward the Sun, and in which the electric propulsion thrusters are linked with this structure via the joint with electric drives.

The solar arrays are designed so as to prevent them from getting in the propulsion plumes during turns.

The mutual arrangement of the Interplanetary Orbiter elements and systems will make for autonomous operation of each element in performing different tasks.

3.5.3. Peculiar features of Interplanetary Orbiter elements

3.5.3.1. Interplanetary Orbiter

3.5.3.1.1. Composition and configuration

The Interplanetary Orbiter (IPO) is the major part of the Complex and is where the crew will work throughout the mission. All the primary instrumentation of the Complex is accommodated here.

The IPO must have a minimum volume available for normal crew activities. It should be rather compact to enable effective radiation protection for the vehicle's living quarters through using the propellant stock planned for the interplanetary flight. (Fig. 10)

The IPO design and configuration must be chosen with regard to the employment of launchers that are expected to be available by the time of the first mission, including Proton modifications.

Following from its purpose, the IPO is actually similar to the Service Module of the International Space Station (ISS). A difference is that required equipment can be delivered to the ISS by Progress in 2–3 months, whereas for the Martian mission delivery time will be 2–2.5 years. Therefore, all hardware that could be needed within this time, including that for contingency situations, should be accommodated in the IPO.

Modular and functional redundancy is enhanced for all systems of the IPO, as compared to the Service Module of the ISS. This is why the vehicle mass is increased from the 20 tons of the Service Module to 60 tons.

The vehicle design consists of three modules: a habitation module and two stowage modules. The functioning hardware and crew are accommodated in the habitation module. This module also accommodates all life support equipment for the crew, including water supply systems, the atmospheric composition control system, and the nutrition system. The habitation module contains all necessary equipment to support the crew's physical abilities during a prolonged flight under space conditions: stationary bicycle, treadmill, small radius centrifuge, g-simulation suits, etc. To perform medical monitoring and render medical aid, a set of medical equipment will be on board, including surgical instruments.

The total volume of the habitation module is 180 m^3. That will allow a crew of 4 to work normally for 2.5 years. The living quarters, including four individual crew quarters, occupy 56 m^3.

This module is provided with a special radiation shield made of tanks containing a working medium. The shield provides a high level of protection while passing the Van Allen belt as well as protecting against sun radiation and flares and galactic X rays.

To ensure crew safety in the event of a fire, the habitation module is divided into two compartments by a pressure shell with a hatch. In each of the two compartments, the crew would be capable of working and controlling the flight of the Complex for at least a month. Any contingency or emergency that could happen in this period should allow for recovery. While repairs are made, the two compartments would be isolated, and egress to space would be possible from each. (Fig. 11).

The two stowage modules are designed as compartments to accommodate instruments and equipment to be used as replacements for exhausted functional equipment in the habitation module or in the event of any system failures. The crew is assumed not to stay in these modules for any long periods of time.

3.5.3.1.2. Reusability highlights

The utilization of electric propulsion is remarkable for the low cost of the working medium needed to inject the orbiter flying from Mars into the low Earth orbit.

With this design, it would be possible to reuse the orbiter without lowering the crew safety factor. The modular and functional redundancy provided on the 20-ton core module of orbital stations was enough to handle safety work for the crew without providing for an emergency abort of the mission. In the 60-ton Martian manned vehicle, the crew will be as safe as on the orbital station.

It is clear, from analysis of all failures that have occurred on orbital stations over more than 30 years of operation, that vehicle reusability will not reduce crew safety, provided that onboard hardware redundancy is sufficient. (Fig. 12).

In regard to turnaround maintenance, the interplanetary vehicle hardware could be kept functional for 15 years, just as on the ISS. In 2.5 years, the vehicle will returns to the low Earth orbit with only 15% runout of its firing cycle. There is no evidence to suggest that the newly developed vehicle will be more or less reliable than already verified in real flight.

3.5.3.1.3. Radiation protection

Outside the Van Allen belt, the vehicle will be exposed to severe galactic X rays and solar radiation, especially during flares. This imposes specific requirements on the whole Complex design. Assuming normal rates of exposure, with the crew exposed to a dose of up to 30 Sv throughout a 1-year flight and up to 75 Sv over a period of 2.5 years, the habitation module must have a protection shield of not less than 40 g/cm^2.

In the project as designed, with the propellant stock available to return the whole Complex to low Earth orbit, the propellant mass will vary throughout the mission from 280 to 30 tons. The radiation protection level therefore will also vary during the mission, from 100 g/cm^2 (during ascent from Mars) to 40 g/cm^2 (before braking in Earth's atmosphere).

Along with the protection provided by the instrumentation and water stock, the use of propellants as a protective layer outside the habitation module solves the problem of protecting the crew from radiation.

3.5.3.2. Solar Tug

The solar electric propulsion is designed so as to be employed for transportation via interplanetary trajectories of any hardware, not only the Interplanetary Orbiter. That is why this propulsion unit is referred to as a "Solar Tug."

The Solar Tug is remarkable because of its large solar arrays, having an area of up to 150,000 m^2. The solar arrays must be designed with concern for the needed rigidity of the whole structure, relative ease of assembly together with the solar arrays, and the possibility for the ground assembling tests.

The structural trusses for installation of frames with film solar arrays are derived from the transformable trusses verified on Space Station Mir («Sofora»). The solar array truss structures are made rigid through the selection of the proper truss cross section, lack of clearances in the joints through use of the so-called shape recovery effect, and the "angular" location of modules relative to the photovoltaic converters. (Figs. 13 and 14).

The solar propulsion unit is of modular design. Each of 72–96 independent modules contains part of the solar array surface, a group of electric power converters, some of the tanks containing the working medium, a group of electric propulsion engines including their own control system boxes, and independent turning drivers.

Such a design is possible only for the solar electric propulsion units. The design considers the issue of invulnerability: even if some of the modules fail, mission performance is not seriously affected.

3.5.3.3. Ascent-Descent Vehicle

The Ascent-Descent Vehicle (ADV) will transport the crew, hardware, and science equipment from the near-Mars orbit to the Martian surface to carry out research programs. Later, it will return the crew and exploration results to the Interplanetary Mission Complex. The ADV's architecture contains the following main elements: a descent module with a braking and landing propulsion unit, a habitation module, and an ascent module with a crew cabin.

The ADV has severe requirements for reliability. The Martian ascent and descent trajectories are rather critical with regard to possible redundancy, transience, spread of parameters, and uncertainty.

The phase of descending to and landing on the Martian surface is the most critical from the crew safety viewpoint. The parachute rocket system used in the final descent phase will take full advantage of the planet's atmospheric capture. Such a braking system gives the ability to reduce the mass consumption for the soft landing system, as compared to an all-rocket soft landing system.

However, a number of technical complexities associated with putting a large, multi-canopy parachute system in the supersonic flow reduces reliability of a parachute system. That is why it would be reasonable to reject the parachute system and use air braking of the descent module primary structure in combination with soft landing by means of a rocket braking system. The rocket system improves landing accuracy.

The landing system will perform the following operations: orbit reboost by means of liquid propulsion to transfer to a landing trajectory, braking by means of the primary structure with an air drag coefficient control to improve landing accuracy, and braking and soft landing via liquid propellant jet engines. (Fig. 15).

While landing, the crew resides in the ADV module cabin so as to be able to return to the vehicle in the event of contingencies at any moment of descent.

While working on the Martian surface, the crew will live in the habitation module.

4.0.0. Highlights of the first missions

4.1.0. Safety concerns and rationale for first missions without a crew landing on the Martian surface

In designing a mission to the Martian surface, crew safety is considered critical. The existing safety requirement (crew safety return probability = 0.995) is unprecedented for such a difficult endeavor as a mission to Mars and will require specific technical solutions to be made. At present, there is no reason to relax this rather severe requirement. In other words, the mission to Mars must not be any less safe than activities on orbital stations where a whole system for a crew rescue in contingencies is available. For the Martian mission, standard requirements such as functionality with two independent failures are already insufficient.

As mentioned above, the Interplanetary Complex elements are such that the Solar Tug and the orbiter allow for high reliability of the interplanetary flight via multiple redundancy. For example, the Solar Tug is composed of a large number of modules containing their own solar arrays, converters, sections of tanks, control boxes, and engines operating independently. The orbiter has modular and functional redundancy.

As for the Ascent-Descent Vehicle, the ascent and descent processes will proceed very quickly, and mode redundancy is very limited. Reliability of the ADV could be ensured (besides through redundancy), by thorough testing, including tests in the real Martian environment. (Fig. 16).

No one appears willing to risk landing a man on Mars unless the ADV automatically descends to and ascends from the planet. Therefore, in the first mission to Mars a crew will not descend to the surface.

4.2.0. Crew virtual landing features

Fig. 17 shows the Complex configuration for the first missions to Mars, with a crew not descending to the Martian surface but instead staying in the near-Mars orbit. Only remote control spacecraft will descend to the surface. This step of human exploration of Mars merits special attention. Essentially, only the cosmonauts’ eyes and hands descend to the surface. This mission efficiently combines crew safety and employment of scientists’ intellect and intuition. The full human virtual presence on the real Martian surface is achieved. This is impossible to achieve from Earth because of the tremendous distance and the corresponding signal delay ranging from a few minutes to an hour.

With regard to operation efficiency, there is little difference between physical and virtual human presence on the surface. As it is, a cosmonaut makes observations not through his or spacesuit window but instead via rather advanced video tools, and rather than using pressurized gloves for hands-on work, he or she employs more delicate instruments.

One of the major goals pursued by the Martian mission is to get ready for Mars settlement. First missions limited to virtual rather than physical landings are first steps toward this goal.

5.0.0. Validation of technical solutions for Martian missions through flight tests

5.1.0. Verification of technical solutions

Technical solutions to problems involving the Martian Complex are verified and validated on special models within the experimental development program. This is consistent with the technology routinely used for ground processing of spacecraft.

In addition, experimental models for the Martian Complex—predecessors of the Complex elements themselves—need to undergo flight tests. The experimental models will be tested in the low Earth orbit. Because the Earth's atmospheric characteristics are very different from those of the Mars atmosphere, the experimental models of the Complex elements must also fly to Mars.

The opinion is widely held that it is natural to regard missions to the Moon's atmosphere and to the Moon as steps toward Martian missions. Fig. 18 shows that the technical solutions for the Martian mission will be validated on the Earth, in the low Earth orbit, and necessarily in the real Mars environment. Missions to the Moon would not contribute to the last type of validation.

The Martian Complex elements will undergo flight tests in the following sequence. Modes of the Complex's flight in the interplanetary trajectory will be verified on simplified models of the Martian Complex («Module 01», «Mars-Module»). Different assemblies and systems of the Complex will tested on the International Space Station. Dynamics of the Crew Return Vehicle re-entry at the second orbital velocity will be verified on a full-sized model of this vehicle. Ascent-Descent Vehicle models will be tested in the upper layers of the Earth's atmosphere (Fig. 19).

5.2.0. Flight testing plan

The plan of work on preparation of the mission is shown in Fig. 20. Before the first mission, it is necessary to construct experimental models, such as for «Module M» and «Mars-Module», to verify certain systems on the International Space Station and to test some modules (in particular, the Ascent-Descent Vehicle), in the Earth's atmosphere. Assuming that the decision to start work is made in 2004, the first mission to Mars, with a virtual landing on the Martian surface, will be possible in 2014. In that timeline, a physical crew landing will take place in 2020. If the decision to start work is made later, other elements of the schedule will be delayed to allow for the fact that the opportunity of launching trips to Mars occur approximately every 2 years.

If the mission with a virtual crew landing is feasible in 9 years from the moment of the decision to start work and if the schedule relies only on proven production cycles, the real crew descent to the Martian surface 5 years after the virtual landing appears to be somewhat conditional. This conditional assumption is bound with the uncertainty of how many landings of the Ascent-Descent Vehicle will be required in the automatic mode to ensure safety. It is the process of the Ascent-Descent Vehicle testing in the real Martian environment that will determine the interval between the virtual and actual crew landings on the Martian surface.

5.3.0. Russian technologies for manned missions to Mars

Russia has already progressed a long way toward the first human mission to Mars. Fig. 21 shows the state of the art of Martian mission technologies. It should be noted that the Ascent-Descent Vehicle represents an absolutely new design. The major concern is for its testing in the real Martian environment.

As for the first missions with the virtual crew landing, their readiness is rather high. About 90% of all the vehicle systems are available and have been tested in flight. The film photovoltaic converters are in production for ground applications. Over the past few years of Station Mir operation, the prototypes of these photovoltaic converters were installed on the station exterior and exposed for 1.5 years, whereupon the prototypes were returned to Earth for analysis. The results proved their stability in flight. The transformable truss structures were also verified on station Mir. Different options for transformable trusses, such as "Mayak," "Krab," "Topol," and "Sofora," were installed on orbital stations. It has been decided that the structural trusses of solar arrays for the Martian Complex will be derived from the truss “Sofora,” using the shape recovery effect to make no-gap joints.

Although a large part of the path toward the first Martian missions is already behind, much is left to travel. Performance of the electric propulsion system needs to be increased to desired values. The vehicle will have new systems to be developed. Among these systems are radio communications, navigation systems, additional medical equipment, e.g. a centrifuge, etc. The automatic remote control spacecraft is a totally new design. (Fig. 21).

5.4.0. Assessment of project failure risks

With respect to its elements and tasks the Interplanetary Orbiter is very similar to core modules of orbital stations. To increase service life and enhance the hardware reliability at the expense of deep redundancy seems rather feasible. The pressure shell production flow, for example, already has been tested and debugged by the manufacturer.

The technology for large film converters is already available. On the whole, it is clear what switching and converting system will be employed. It is still necessary to verify the technology for assembling the solar array modules and their installation on the structural trusses. Some problems are likely to arise, but solutions appear to be possible.

Different designs of transformable truss structures have been verified. A reference model of solar array deployment and assembly has been developed. No unsolvable problems have been encountered thus far.

The electric propulsion engines are functioning. The way that acceptable performance may be achieved is clear.

Development of the Ascent-Descent Vehicle is the most critical process. It appears feasible to develop an Ascent-Descent Vehicle that, instead of parachute systems, employs landing engines using hypergolics. The major problem is how to ensure safety during descent to the Martian surface. The vehicle needs to be verified, including tests in the Martian environment.

The Crew Return Vehicle has many prototypes. Re-entry to the low Earth orbit from the Sun orbit has to be verified to make sure that quarantine measures will be taken before the crew lands on Earth. (Fig. 22).

6.0.0. Possible application of Martian Mission Complex elements to other programs

The key elements of the Complex are designed as independent products that have potential uses in other space programs. For example, the power station of 15 MW could be employed in power intensive production in the low Earth orbit. The Solar Tug could be used to transport cargo between the Earth and the Moon orbits. Essentially, the Interplanetary Orbiter could serve as an orbital station.

CONCLUSIONS

The proposed concept for the Martian mission offers the following advantages (Fig. 23):

- A high probability of safe return of the crew in the first missions, with virtual landing, is achieved through multiple redundancy of the Interplanetary Orbiter and Solar Tug hardware and systems. In missions when part of the crew lands on the Martian surface, crew safety is ensured by multiple tests of the Ascent-Descent Vehicle without the crew in the real Martian environment.
- Within the proposed scenario, mission costs will be at a minimum, with respect to both the Interplanetary Complex itself and its ground testing facilities. Because the Interplanetary Complex has the minimum launch mass, the number of launchers needed to insert it into orbit is also reduced to the minimum. No sophisticated and expensive testing facilities have to be developed to validate or test any of the technical aspects of the Complex.
- The electric propulsion system and solar arrays give the ability to make the vehicle reusable. This, in turn, enables expansion of the flight test program and considerably reduces the costs for the whole Mars exploration program.
- The flight tests of the Ascent-Descent Vehicle during its flight to Mars without the crew will not only enhance safety but also give the ability to effectively explore the Martian surface. In such missions, in addition to exploration by means of virtual human presence on the surface, it would be possible to descend probes containing research equipment of large mass.
- Ecological safety of the Interplanetary Complex propulsion will provide technological benefits and project support by the world community.

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2. RSC Energia projects
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4. Selection of propulsion
5. Selection of launcher
6. Crew
7. Program
8. Interplanetary Mission Complex (IMC) = ___
9 Elements, mass
10. Interplanetary Orbiter (IPO) = ___
11. IPO, configuration
12. Failures
13. Solar array
14. Truss solar array
15 ADV (Ascent-Descent Vehicle)
16. Safety
17. Overall view of IMC, automat
18. Testing ideology, the Moon
19. FT objects
20. FT program
21. Status
22. Risks
23. Assessment