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Robots for a Detailed Study of Moon

Oleg Saprykin[1] and Oleg Tolstel[2]

Abstract---*The problem of a detailed study of the Moon is considered - the phase of the study in which a person has either not yet begun manned flights, or makes them no more than once a year. At this phase, it is very important to conduct detailed studies of the substance in various regions of the moon, which should directly affect the pace, scale and scenarios of the exploration of the moon. The authors, relying on a list of scientific research on the moon that is relevant for the coming decades, offer the appropriate tools - automatic and semi-automatic (with elements of artificial intelligence) robots. It is shown that scientific tools and the necessary robotic systems can be unified and reduced to a relatively small list.Of particular interest is the reusable use of scientific equipment and related robotic systems. Reusable execution of robots, their maintenance on the lunar surface by robots themselves or on board a near-moon station can significantly reduce the time of exploration of the moon and go to the phase of its development - the pace of research can be increased by an order of magnitude. A key element in the proposed concept should be a reusable take-off and landing vehicle (MVPA). Its creation will ensure the reusability of the use of robots on the moon. In addition, the authors conclude that it is necessary to deploy an automatic lunar orbital station (LOS) in a low lunar orbit, the main task of which will be the maintenance of replaced equipment and the refueling of MVPA.Authors present configurations of promising robot platforms for scientific equipment for a detailed study of the moon. Features of the use of anthropomorphic robotics on the moon are considered separately. Recommendations are given on its use, implementation of elements of the artificial intelligence system. In combination with proposed MVPA concept and reusable scientific equipment, the use of anthropomorphic technology will ensure the telepresence of research scientists on the moon, regardless of the fact and speed of manned flights.*

Keywords: *Scientific Equipment, Drilling Rig, Deep Logging Tool, Reusable Take-Off Vehicle, Lunar Orbital Station, Anthropomorphic Robot, Low Lunar Orbit, Operator, Avatar, Partially Intelligent Control Mode, Signal Delay.*

I. INTRODUCTION

For the exploration of the moon, as many space agencies today claim, it is necessary to know its substance. Much depends on the availability of certain local resources: the appearance of the lunar infrastructure, flight scenarios, the pace of launches, the scale of human presence. Actually, the natural resources of the moon and constitute the main object of exploration. The moon has been the subject of direct scientific research for more than 50 years. However, today it cannot be said that mankind has studied the Moon so well that it can begin the

[1]*Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences, 119991, Moscow, Kosygin Street, 19, +79163275591, E-mail: oleg.sapr@gmail.com*
[2]*Baltic Federal University name of ImmanuilKants, 236020, Kaliningrad, A. Nevskogo Street, 14, +79097759163, E-mail: tolstel.oleg@mail.ru*

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construction of inhabited (visited) settlements and begin to use the resources of the moon. To date, studies have been conducted using separate scientific missions with automatic spacecrafts (SC). In the late 1960s and early 1970s, six US manned expeditions visited the moon (Apollo program). Of course, manned flights gave a lot of valuable information. At the same time, the organization of manned flights to the moon is an extremely expensive task. So expensive that after 40 years, no one can repeat it yet.

If we use automatic spacecrafts with the intensity of the missions that were up to now, then the stage of studying the moon will clearly exceed one or even two centuries. Of course, it is impossible to explore Moon for a millennium. Humanity has been exploring the Earth for its entire history. In this case, by the stage of research, we mean obtaining only that knowledge about the material of the Moon, its nature, which may be sufficient for manned missions - justifying these missions, this is knowledges of the preparation of human presence. It is unlikely that the duration of the study phase in such a context for several centuries can be considered acceptable.

This means that it is necessary to more carefully consider the capabilities and effectiveness of the missions performed by automatic spacecrafts. It is necessary to analyze the composition of the used scientific equipment, types of platforms for the placement of scientific equipment, flight scenarios. This is the part of the design and analytical work that defines the necessary lunar infrastructure, creating even before man will on Moon. This kind of work has already begun within the framework of the European Space Agency (ESA), the Japanese Space Agency (JAXA), the Canadian Space Agency (CSA) [1]. The HERACLES project was one of the first in this direction to be actively discussed in international cosiety. However, the technical solutions laid down in the HERACLES project are largely related to another large-scale international project - LOP-G (Lunar Orbital Platform-Gateway) [2]. This article is devoted to the consideration of these issues without direct reference to any projects (international or national) - in a more general setting. In addition, it was proposed to more carefully consider the possibility of the telepresence of a human researcher (scientist) on the moon through the use of anthropomorphic technologies. This is the most important issue that can remove the need to complete entire missions with automatic spacecraft or even, in some cases, to perform manned flights.

A. Actual scientific tasks on the surface of Moon

Priority (topical for the next ten years) scientific tasks related to the need to land automatic spacecraft (SC) on the lunar surface can be systematized as follows.

1. Study of the composition and physicochemical properties of the regolith;

2. The study of the thermophysical properties of the regolith;

3. The study of the volatile components of the regolith: implanted, loosely coupled and frozen;

4. Study of the structure of the moon (study of the history of the formation of the regolith, the internal heat flow of the moon, seismic studies);

5. Study of the radiation situation and radiation anomalies on the moon;

6. The study of lunar rocks as a raw material for extraterrestrial construction;

7. The study of lunar rocks as raw materials for the production of extraterrestrial fuel;

8. The study of lunar rocks as raw materials for the production of semifinished products of extraterrestrial metallurgy.

Each problem to be solved corresponds to a certain scientific equipment. Based on the experience of space flight, the existing scientific and technical groundwork, it is possible to form a table of scientific equipment, estimate its mass and the minimum number of experiments with this equipment on the lunar surface, which generally provides the initial stage of the lunar exploration, Table 1.

Table 1: Required scientific equipment at the initial stage of the Moon's exploration

Scientific task on the moon surface	*The content of the experiment*	*Necessary scientific equipment (SE)*	*Weight of SE, kg*	*The minimum number of experiments, pcs.*
1.	2.	3.	4.	5.
1. Study of the composition and physicochemical properties of regolith	Taking samples of the regolith for delivery to Earth	Drilling rig (75 kg), container for placing a stratified column (25 kg)	100	6
2. Study of the thermal properties of regolith	Temperature measurement at depth and their annual dynamics	Deep thermal sensors, penetrator	8	6
3. The study of the volatile components of the regolith: implanted, loosely coupled and frozen	Sampling in sealed containers for delivery to Earth, the study of volatile components during drilling	Drilling rig (75 kg), mass spectrometer (15 kg), hermetic container for placing a stratified column (25 kg)	115	6
4. Study of the structure of Moon (study of the history of the regolith's formation, the internal heat flow of Moon, seismic studies)	Study of the distribution of different layers of regolith in depth, Measurement of temperatures at depth and their annual dynamics	Deep logging probe, penetrator, seismometer	8-10	10
5. Study of the radiation conditions and radiation anomalies on the Moon	Measurement of background radiation at the surface and at depth	Various types of ionizing radiation detectors, deep logging probe	1-2	12
6. The study of lunar rocks as a raw material for extraterrestrial construction	Delivery to Earth of samples for technological research	Drilling rig, hermetic container for delivering samples to Earth	100	12
7. The study of lunar rocks as raw materials for	Delivery to Earth of samples for technological research	Drilling rig, hermetic container for delivering	100	12

Scientific task on the moon surface	*The content of the experiment*	*Necessary scientific equipment (SE)*	*Weight of SE, kg*	*The minimum number of experiments, pcs.*
extraterrestrial fuel		samples to Earth		
8. The study of lunar rocks as a raw material for the production of extraterrestrial metallurgy	Delivery to Earth of samples for technological research	Drilling rig, chemical analytical module, hermetic container for the delivery of samples to Earth	150	12

As you can see, part of the nomenclature of scientific equipment (AT) for various scientific tasks is repeated, and the number of uses of this equipment in experiments on the lunar surface is dozens of times. Thus, the nomenclature of NA for research on the surface of the Moon can be systematized by highlighting the typical NA, the use of which will be required repeatedly.

An important indicator is the number of required experiments. For example, the number of necessary landings on the surface of the moon, if we assume one-time flights under the scheme "one experiment - one mission", is more than 70 space missions. Of course, in this case, the process of exploring the moon could exceed 100 years, which is hardly consistent with the plans of many space agencies.

B. Typing and reusing scientific equipment on Moon

How can the number of space missions be reduced without reducing the number of space experiments on the moon? In other words, how to shorten the duration of the first (exploratory) stage of the Moon exploration? The author suggests using two known methods:

The first method is thematic integration of scientific equipment on board.

The second way is to use the same scientific equipment many times.

If we combine the solutions of various tasks within one mission, then the mass of scientific equipment for the study of lunar matter will be from 100 to 162 kg Clusters (sets) of such equipment can be used many times, they can be repeatedly transported to new areas of the Moon, which shortens the duration of the moon exploration stage by a dozen times.

In particular, the most important is the use of a reusable drilling rig (RDR, Fig.1, [3]) and a reusable deep-well logging probe (RDLP, Fig.2, [4]), having a total mass of about 160 kg. In addition, a sealed container for the delivery of samples to Earth, including a cassette with a stratified regolith column, is a necessary element (Fig. 3).

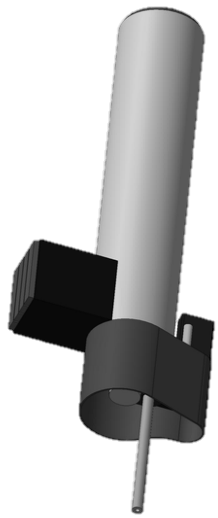

Fig.1: Reusable drilling rig (RDR).

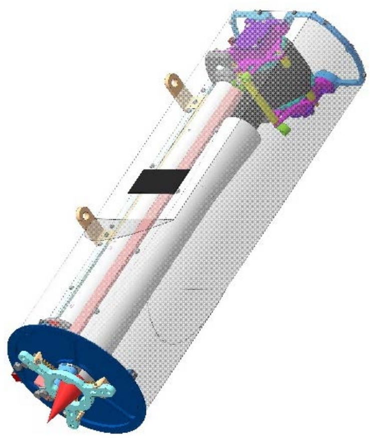

Fig.2: Reusable deep logging probe (RDLP).

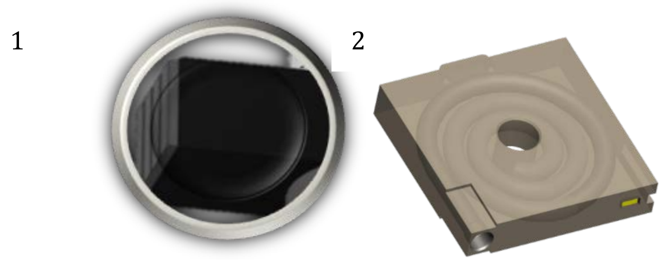

Fig.3: Sealed container for delivery of samples to Earth (1). Cassette for storing a stratified regolith column (2).

At the same time, the mass of the stratified regolith column for a single intake into a cassette is 3.4 kg. The depth of drilling can be up to 6 m. The mass of the container for one cassette will be about 25 kg.

At each experiment of drilling the lunar surface, a replaceable (replaced) piece of equipment will be required. The mass of such "one-off" equipment is about 50 kg for each drilling.

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C. Robotics serving scientific equipment

Not only before the start of manned missions to the moon in the 21st century, but also after that, robotics will be needed to service scientific equipment (SE) on the moon. Robotics is a very broad concept, so we will consider the part of it that is directly related to the maintenance of scientific equipment. Here it is important to distinguish three types of tasks that robotics will face.

The first type is transport tasks, i.e. transportation of SE from one region of the Moon to another;

The second type is the solution of standard manipulation problems in a deterministic environment;

The third type is the solution of manipulation problems (standard and non-standard) in a non-deterministic setting.

Accordingly, these three types of tasks can be used to formulate three types of robots that will be needed for maintenance of scientific equipment. It:

For the first type of tasks - the rover (moon rover), Fig.4;

For the second, a manipulator with 6 or 7 degrees of freedom, Fig.5;

For the third, there is an anthropomorphic type manipulation complex that includes two manipulators with several dozens of degrees of freedom, the torso part, the telepresence navigation system, Fig.6.

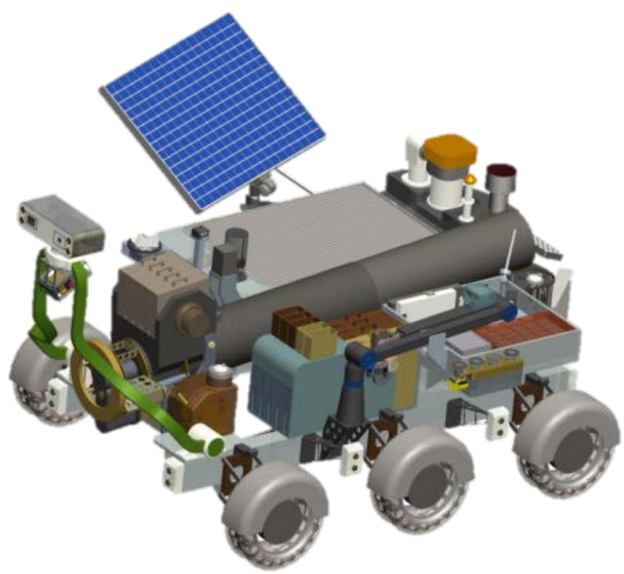

Fig.4:Lunokhod for transportation of reusable scientific equipment [5].

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Fig.5: Manipulator for working with cassettes, containers (for standard operations - overload, fixing, installation, removal) [6].

Fig.6: Android robot for fine manipulations (studying stones, repairing equipment) and for working with an anthropic-like geological instrument [7].

D. Reusable scientific equipment delivery vehicles.

The use of reusable scientific equipment also involves the use of reusable means of delivery, namely, the reusable landing gear (MVPA), carrying out from circumlunar orbit to various regions of the Moon and delivering lunar matter samples to orbit for subsequent delivery of samples to Earth. This is the most important element of the entire infrastructure for scientific equipment, without which the idea of reusable scientific equipment (and, therefore, an active comprehensive study of the Moon) will not have such a meaningful perspective.

As part of the research carried out by the author [8], flight scenarios where the landing of automatic spacecraft on the lunar surface is combined with the maintenance of these spacecraft in low lunar orbit have tremendous advantages in relation to single (one-time, maintenance-free) flights of spacecraft with similar volume of tasks, and in relation to manned missions to the surface of the moon.

In fig. 7 shows one of such scenarios, when the spacecraft in the form of MVPA performs up to six landings in distant regions of the Moon. At the same time, the service is a refueling in a low lunar orbit from a tanker (space tug), waiting for MVPA in an orbit with an altitude of 100-200 km. Under this scenario, two variants of the IMPA were considered. The first version of MVPA is a two-stage, partially reusable MVPA, when the landing stage remains on the Moon after each landing (it is filled with a new one in orbit), and the take-off stage is reusable and refillable. The second version of the MVPA is a fully reusable, single-stage MVP, refueling in orbit. The dimension of the complex of scientific equipment corresponds to the dimension of the spacecraft "Luna-Resource-1 (PA)" - about 90 kg. Thus, two launches of heavy-class carrier missiles provide a solution to the tasks corresponding to six separate missions of the Luna-Resource-1 (PA) mission.

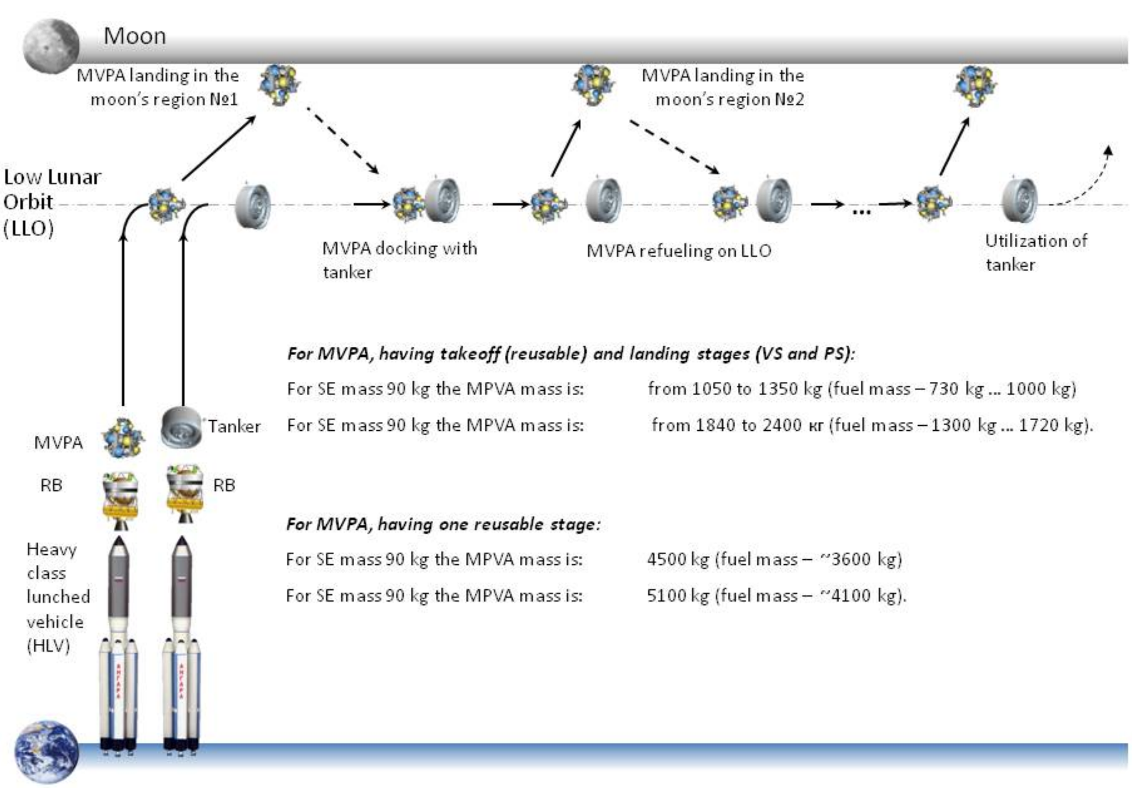

Fig. 7: The mission scenario of an automatic spacecraft in the MVPA variant, when up to six distant regions of the Moon are investigated and refueling is used in low lunar orbit.

As we can see from the cited calculation results, a two-stage, partially reusable MVPA turns out to be of a lower dimension than a fully reusable one-stage one. However, in reality, in the first case, we must also deliver six filled landing stages together with the tug. This may be more complicated and more expensive than the delivery of only one fuel, albeit a larger mass. If we turn to the issue of optimizing the height of the orbit for refueling MVPA, here the results of ballistic calculations look quite clearly, Fig. 8 [9].

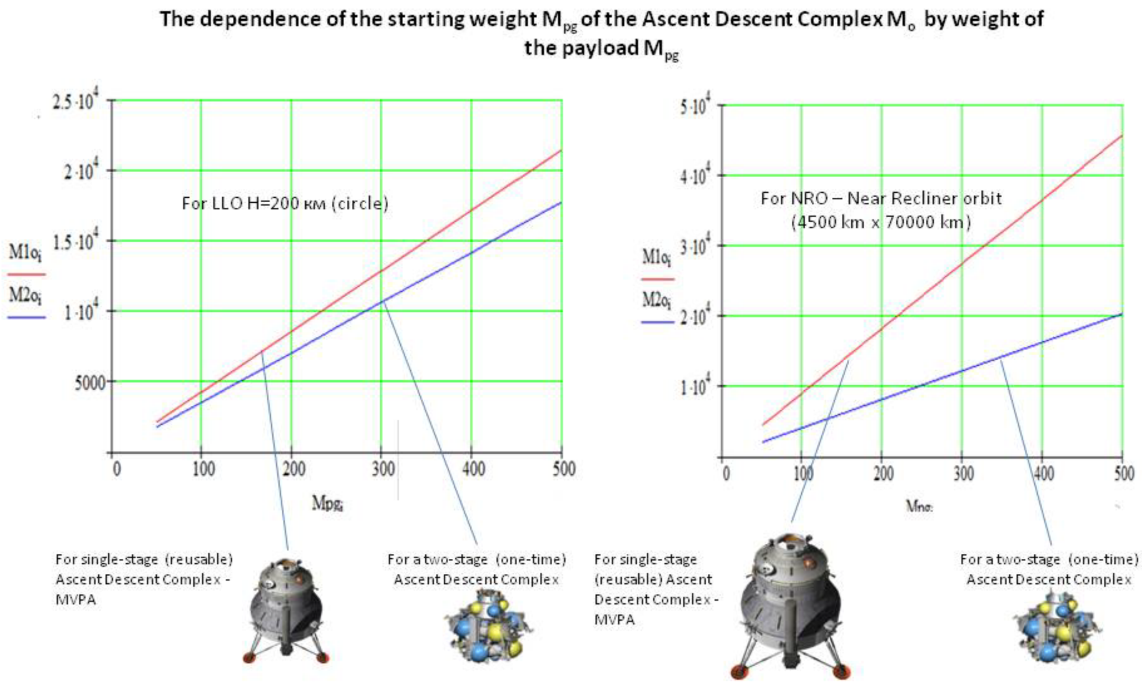

Fig.8: Dependence of mass of MVPA on execution, mass of AN and on the height of the orbit of refueling.

In Figure 8, the left side shows the graphs of mass calculations of the MVPA for the refueling variant on a circular polar lunar orbit of 200 km in height, and on the right side are calculations for the variant of delivery of the MVPA to the high polar lunar orbit (Near Recliner orbit, NRO) with altitudes of 4000 km ... 70,000 km chosen as the base for the LOP-G project (Lunar Orbital Platform-Gateway) [2]. As we can see, first, the dimension of the MVPA is several times (an order of magnitude) in the variant of refueling in a low lunar orbit less than in the case of a high orbit NRO. Secondly, the differences in dimension between the two-stage and single-stage MOPA for low orbit refueling are not as significant as in the case of refueling in NRO orbit. The option of a fully reusable MVPA becomes irrational if we raise the altitude of the refueling orbit. In the case of using low orbit for refueling, fully reusable MVPA look quite competitive in relation to the two-stage (partially reusable) MVPA execution options.

E. Лунная орбитальная станция

The consequence of the ideas and calculations outlined in the previous sections is the conclusion about the need to create a lunar orbital station - LOS. In particular, its tasks, localization in the lunar space, and dimensionality become obvious.

Table 2 lists the main tasks that can be performed on board a LOS, the requirements for human presence arising from these tasks, the need for specific equipment.

Table 2: Potential problems solved onboard the LOS and necessary means

The potential problem it possible to solve on board of LOS	*Necessary equipment*	*The necessity of human participation*	*Remark*
1	2	3	4
1. The contact study of the lunar matter (regolith samples delivered by the WPA)	Chemical-analytical laboratory, thermal vacuum chamber, thermal oven, mass spectrometers, microscopes	Desirable	The effectiveness of a scientific survey is determined by the number of specialists involved in the work. With one or two specialists in orbit, only express analysis is possible, not replacing the need to deliver samples to Earth
2. Remote study of the moon	Cameras, camcorders, spectrometers, IR and UV cameras	Not required	Crew participation is required only for conducting operational surveys, when shooting sites are difficult to predict and identify.
3. Space astrophysics research	Telescopes, radio telescopes, magnetometers	Not required	Being on board the crew is undesirable with active equipment
4. Overloading samples of lunar matter from the WPA to the ship returning to Earth	Robot arm	Not required	
5. Refueling of VPA	Refueling system	Not required	
6. Retrofit of WPA with replaceable scientific equipment	Robot arm	Not required	Subject to the modular manufacture of scientific equipment
7. Repair of VPA	Robot arm, Anthropomorphic robot	Not required	Subject to repairable manufacture of VPA
8. Development of new technological or technical solutions in deep space conditions	It is impossible to describe the necessary equipment in advance.	Desirable	The frequency and scale of the formation of a package of such tasks is currently difficult to assess. It is expected that at the initial stage of the study of the moon such problems will be few.
9. Logistic support for manned flights to the surface of the moon	Interfaces for docking of manned spacecraft and lunar modules. Life support systems for temporary stay of the crew.	Determined by the mission scenario	For manned flights to the moon

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The potential problem it possible to solve on board of LOS	*Necessary equipment*	*The necessity of human participation*	*Remark*
1	2	3	4
10. Operational support for remote control of robots on the surface of the moon	Communication systems with orbital near-moon repeaters that set (control) the device robots	Is required	With manned flights to the moon and the deployment of robotics on the surface, working on flexible scenarios (requiring adjustment by the operator)

As follows from the analysis of table 2, in the overwhelming number of cases, if this visit to LOS is not tied directly to a manned mission, it is not necessary to have a person on board. That is, LOS is a predominantly unmanned orbital object, significantly different from near-earth manned stations.

What may be the approximate appearance of LOS, gives an idea of Fig.9.

Fig.9: LOS, preliminary conception.

Taking into account the listed tasks, the characteristics of this type of LOS could be as follows [9]:

Electric power of solar batteries 15 kW;

Marching Electrojet Engine Type SPD-230;

Electrojet control engine type SPD-50;

Xe - filling 300 kg;

The mass in the orbit of the moon - 3777 kg.

An example of the inclusion of such LOS in the scenario of the implementation of the scientific mission is shown in Fig.10. The scenario shown in the figure provides for the interaction of automatic spacecraft with a station in high lunar orbit (for example, with the international project LOP-G). The meaning of the interaction in this case is the use of manned LOP-G related missions as cargo missions for the return of lunar matter samples (scientific results on the surface). Thus, the proposed version of the lunar infrastructure is organically consistent even with those projects whose direction is not directly related to the exploration of the moon. The lunar station in low orbit turns out to be the key object of the lunar infrastructure, since its task is to service the MVPA — their refueling, retrofitting with a spare tool of scientific equipment and radio engineering support of operations on the lunar surface.

F. The appearance of promising scientific complexes

If we relate proposals for the tasks of scientific complexes, variants of robotic means of their maintenance, variants of delivery systems and variants of the lunar orbital station, then the following variants of scientific complexes most fully meet the goals of shortening the stage of scientific research on the Moon.

1) MVPA with a drilling rig and a deep logging probe;

2) a heavy lunar rover with a drilling rig, a deep logging probe, and others. For the study of regolith;

3) lunar rover with the torso part of an anthropomorphic robot for research including stony, rocky rocks and with the possibility of repair (oneself and other lunar technology), Fig.11 [10,11].

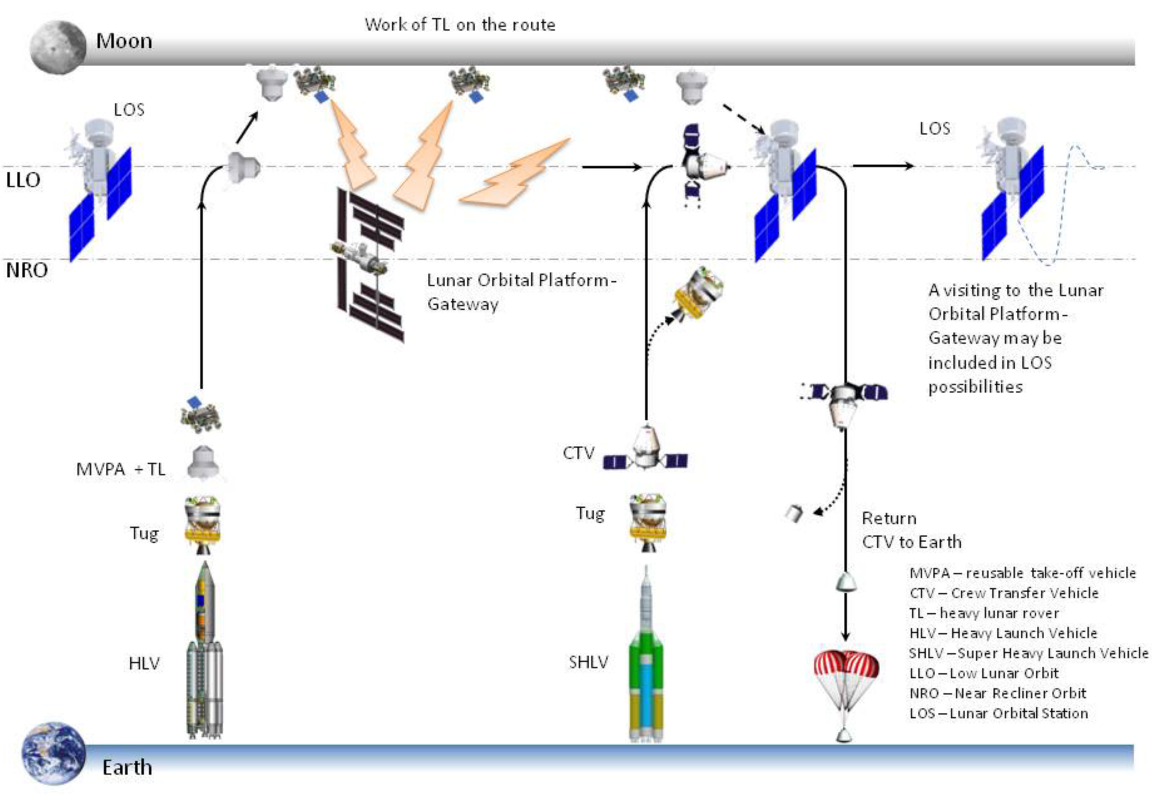

Fig.10: Scenario of using LOS in scientific missions using reusable scientific equipment.

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Fig.11:Lunokhod with the torso part of an anthropomorphic robot for research of stony, rocky rocks and with the possibility of repair (of itself and other lunar technology).

From the point of view of technical implementation, the first two types of platforms for scientific complexes have historical analogues. For example, MVPA with a drilling rig have analogues in the form of the Soviet stations "Luna-16", "Luna-20", "Luna-24" (Fig. 12).

Fig. 12: Automatic Soviet station "Luna-24", equipped with a drilling rig and a part that is rotated to the Earth.

The Soviet Lunokhod-1 and Lunokhod-2 are the analogue of a heavy lunar rover with a drilling rig. The mass of Lunokhod-2 was, for example, 840 kg, [12], Fig. 13.

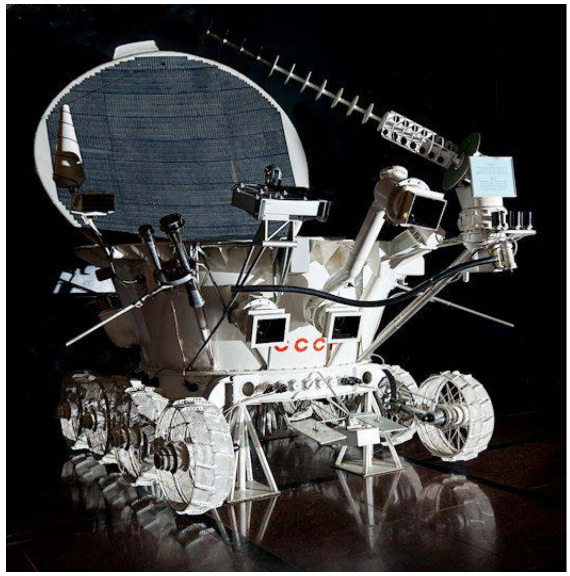

Fig. 13: Soviet Lunokhod-2.

Let us consider in more detail a lunar rover with a torso part of an anthropomorphic robot, since there is no historical analogue here yet.

G. Lunokhod with a torso of an anthropomorphic robot

This solution for the lunar scientific complex is a compromise between the desire to reproduce on the moon manipulators with the exact motor skills of hands, human hands in the form of an anthropomorphic robot, as well as the desire to create a reliable and relatively fast locomotion complex for alien conditions that ensures the movement of all scientific equipment.

Thus, we are talking about creating a system of two interacting robotic complexes - manipulation and locomotion. In general, such a system can be called a “centaur” in honor of the mythical heroes of the ancient Greek epic [13], Fig. 14.

Tasks of such a system are focused on non-standard situations - to work in a non-deterministic environment. This also applies to the navigation of the locomotion complex, and the fine motor skills of the two arm manipulators. The Centaur should solve the following tasks:

- performing manipulations with efficiency comparable to the actions of an astronaut during extra-ship activity;
- high-precision navigation in the external environment both for the operation of manipulators and for moving the entire system in the environment;
- the ability to work with a standard (universal) tool adapted for human work;
- the ability to service (replace) the modules of the system itself, critical from the point of view of the resource;
- locomotion of the system over difficult cross-country terrain at distances of hundreds of kilometers;
- autonomous power supply system;

- temperature control of the system, including periods of moonlit night and active exposure to solar radiation.

When creating such a system there are many difficult tasks. Currently, the authors are studying the following tasks:

1) Control of the system from the Earth under conditions of a signal delay of about 3 seconds.

2) Creating a temperature control system for the temperature range from -180 to +190 degrees Celsius.

3) Creation of a locomotion complex providing for the movement of the system hundreds of kilometers on the surface of Moon.

Without solving these problems, the value of the complex for the moon is greatly reduced.

The delay of the control signal from the Earth to the Moon is about 3 seconds. This significantly complicates the performance of precision operations of fine motor skills by an anthropomorphic robot in the case of using the copy mode. Accordingly, the robot must have an intelligent manipulation control system that would allow it to operate to a certain extent independently. This means the possibility of sequential execution of typical movements with the brush and each individual finger within a certain scenario. Such a scenario may be the capture of a rock sample in the form of a stone of arbitrary shape or routine operation using a typical tool.

To train and improve the performance of each individual movement within the framework of such a scenario, the creation and development of a virtual model of such a robot in a virtual environment, for example, the Unity product, is required [14]. During such testing, the vision system constantly supplies the control system with the current data on the relative position of the manipulation object and all the joints of the manipulator's hand. Based on multiple training solutions to the problem of inverse dynamics and performing manipulations in the copy mode, a knowledge base of the necessary sequences of atomic movements is formed. Such a base is formed in the form of a trained neural network of a certain architecture or a fuzzy controller. In the presence of a large verified base of such scenarios, the telepresence operator only starts the action and further controls its correctness. The robot then picks up the current action, choosing the most suitable scenario from the knowledge base and executing it. After completion of the script, there comes a time when you cannot perform new actions for several seconds, but control the correctness of the previous ones. In this way, a specific control mode is formed, which we will call *"partially intelligent" control mode*.

About the development of a locomotion complex. The need to move it on stony and rocky rocks along inclined surfaces leads to the use of the so-called "Walking wheels." With this design option, the wheel is not mounted coaxially with the mounting bar on the apparatus. Thus, the chassis was implemented on Soviet moon rovers [15], as well as on American rovers (Spirit, Opportunity, Curiosity [16]). In particular, the authors consider the following design: the upper part of the wheel mounting rod is attached to the axis coming from the body, Fig. 11. Inside the housing is an electric motor that can rotate the axis. In this case, the rod with the wheel also moves. When moving on a horizontal surface with small tilt angles, the robot moves only with wheels. When obstacles appear in the form of potholes or placers that cannot be avoided, the robot steps over them. To do this, the design provides for additional retractable bearings (not shown in Fig. 11). The same supports can be extended to increase stability when the robot begins to manipulate. Also, to facilitate pacing, the use of moving the center of mass of the structure by changing the position of the torso is provided.

The combination of the walking and rolling functions should ensure high road qualities of the system. For example, walking can also be applied if the angle of elevation of the surface is large and / or the coefficient of adhesion to the surface is reduced. The torso can lean forward to capture objects on the surface of the moon. If it is necessary to unload one of the front wheels for walking, the torso should be thrown back, while the case with the manipulators should be turned at a right angle from the initial position to the side opposite to the unloaded wheel. Manipulators are also brought to the required position. To unload the rear wheels for walking, the procedure is similar, but the torso part leans forward.

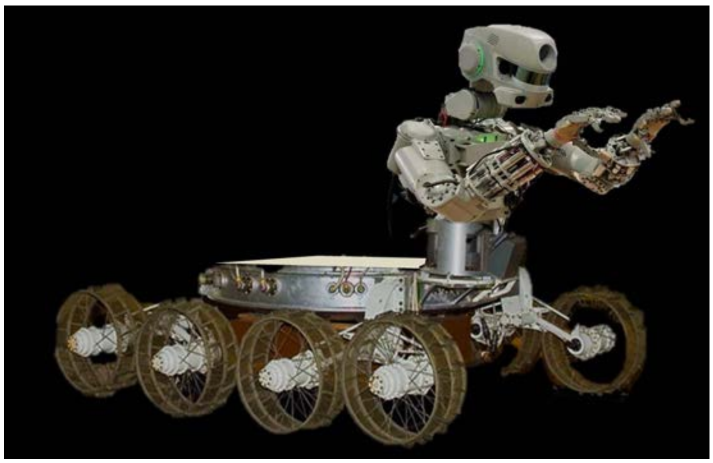

Fig. 14: The variant of the anthropomorphic robot of the Skybot f-850 project on a wheeled-walking chassis of moon rovers.

About the development of a robot temperature control system. Specialists of the Android Technology company and the I.Kant Baltic Federal University conducted thermal vacuum tests of the torso part of the anthropomorphic robot in a thermal pressure chamber of JSC “ISS named after Reshetneva" [17], Fig. 15. Under conditions of maximum heat generation in the manipulator’s engines while simulating the maximum external heat fluxes, the manipulator worked for 1.5 hours before reaching the critical temperature. In the absence of external heat fluxes, when heat was released by radiation onto cryoscreens simulating the surrounding space, it took about 10 W of heat in the manipulator electric motors to maintain temperatures over them in a comfortable range. Thus, the circuit design of the torso part was confirmed, in which the manipulators were not covered by screen-vacuum thermal insulation, and the body was covered. A similar solution is proposed for the lunar variant.

Fig. 15: Thermal vacuum tests of the prototype manipulator of the anthropomorphic robot in the pressure chamber of JSC “ISS named after Reshetneva", manufactured by the company "Android technology"

In addition to temperature control at the drive level, the option of temperature control of the entire anthropomorphic torso of the robot for the period of the "moonlit night" is also being considered. In this case, the locomotion complex has a container in the upper part corresponding to the dimensions of the folded torso of the robot. Before the start of the "moonlit night" the container opens, and the torso of the robot folds into the locomotion complex. After that, the container closes. With this embodiment, heat loss during a moonlit night can be minimized.

Thus, the solution to the problems of creating an anthropomorphic lunar explorer created by the formula "operator + avatar" seems possible.

II. Conclusions

1) The stage of researching the substance of the Moon when using reusable means (MVPA equipped with reusable RDR and RDLP) can be reduced by almost ten times compared with the period of implementation of one-time scientific missions to the lunar surface with a similar volume of scientific tasks and a similar mass of lunar returned to Earth substances.

2) It is necessary to deploy in the low lunar orbit an automatic lunar orbital station (LOS), whose main task is to maintain the MVPA - to refuel them, to equip scientific equipment with spare parts and radio engineering support for operations on the lunar surface.

3) Currently, the tasks of creating reusable tools for scientific research (RDR, RDLP, MVPA) and remotely controlled robotics placed onboard the MVPA, moon rovers and LOS (in particular, cargo manipulators for transferring containers, as well as manipulators for preventive maintenance and repair MVPA).

4) Particularly relevant is the creation of tanker tankers for MVPA.

5) Promising platforms for scientific equipment, which cover the list of topical scientific tasks for the coming decades for a detailed study of the Moon, are:

– MVPA with reusable drilling rig and reusable deep logging probe;

– heavy lunar rover with reusable drilling rig, deep logging probe, etc. science equipment to study the regolith;

– lunar rover with the torso part of an anthropomorphic robot.

6) The proposed concept can be developed both in support of the upcoming manned expeditions to the Moon, and independently of them, providing flexibility and continuity in the implementation of a comprehensive scientific program.

7) It seems relevant to develop an anthropomorphic lunar robot based on a wheeled-walking locomotion platform. Such a combined system can largely replace a human researcher on the moon, giving the researcher on Earth the possibility of telepresence and control in a mode close to that of direct copying.

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REFERENCES

[1] HERACLES. Human/Robotic Lunar Partnership Mission.M.Landgraf, S.Hosseini, B.Hufenbach, E.Martin, M.Picard, D.Lefebvre, J.Hill, N.Sato, K.Laurini, O.Saprykin./ Follow-on Assessment (HRLPM2)// Monografia, ESA: CDF Study Report, CDF-156(A), May 2015, 318 p.

[2] https://ru.wikipedia.org/wiki/Lunar_Orbital_Platform-Gateway.

[3] Problems of research and mining of gas deposits on the moon. E.Slyta. /Mining of Mineral Deposits.ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print).Journal homepage http://mining.in.ua. Volume 11 (2017), Issue 4, pp. 117-125. //https://doi.org/10.15407/mining11.04.117.

[4] About of the development of a deep logging probe for the study of the lunar rocks structure on Luna-Resource-1 spacecraft. O.Saprykin, V.Pogonin /V All-Russian Scientific-Technical Conference “Prom-Engineering”, Sochi, 4.2.6, 2019.

[5] https://www.vladtime.ru/457121-rossiya-vpervye-za-40-let-zapustit-lunohod.html/.

[6] https://studfiles.net/preview/6233539/page:12/.

[7] https://robo-sapiens.ru/stati/robot-fedor/.

[8] The methodology of comparing the effectiveness of different scenario for lunar exploration by manned and automatic means. O.Saprykin, A.Imshenetskiy / 67-th IAC (International Astronautical Congress), IAC-16, IP,7,x32701, Guadalajara, Mexico, 2016.

[9] Roscosmos’ activities in Space Research and Exploration Architecture Analysis. V.Mitin, O.Saprykin/ ISS ExplorationCapability Study Team (IECST) meeting/ Tsukuba, Japan, February, 2017.

[10] About the possibility of use anthropomorphic manipulators and transport robotic systems to create the commercial system for energy, communications and logistics support on the Moon surface. O.Saprykin, A.Imshenetskiy, M. Landgraf /67-th IAC (International Astronautical Congress), IAC-16,B3,2,6,x33865, Guadalajara, Mexico, 2016.

[11] Application of advanced robotics for the exploration of outer space objects by the example of robotics for lunar research. Use of anthropomorphic robots for the further exploration of near-earth space and for the tasks of Lunar and Mars exploration. V. Sychkov, O. Saprykin/66-th IAC (International Astronautical Congress), http://www.iac2015.org, IAC-15.A5.3-B3.6.9, Ierusalem, Israel.

[12] http://epizodsspace.airbase.ru/e2/foto-e2/l-21/l21.html.

[13] N.Kun. Myths and legends of ancient Greece. Moscow: OLMA Media Group, 2012, p. 110.

[14] https://unity.com/

[15] https://studref.com/361480/tehnika/kratkiy_obzor_shassi_planetohodov

[16] Martin, Paul K. NASA'S MANAGEMENT OF THE MARS SCIENCE LABORATORY PROJECT (IG-11-019). NASA OFFICE OF INSPECTOR GENERAL.

[17] P.N. Chubov, O.V. Tolstel, L.Z. Krochak, A.A. Bogdanov and A.A. Shponko «Results of Research Tests of Robot of Anthropomorphous Type Thermal Control System» – Journal of Engineering and Applied Sciences, 12(13), pp. 9444-9450, ISSN 1816-949X, 2017.