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LUNAR ORBITAL PLATFORM SEGMENT FOR SUPPORT AND PROVISION OF LUNAR SURFACE MISSIONS

D.Zarubin [a]*, N.Sevastiyanov [b], E.Mikrin [c], R.Beglov [d], Y.Makushenko [e]

[a] *Moon exploration program R&D Center, S.P. Korolev Rocket and Space Corporation Energia, 4A Lenin Street, Korolev, Moscow area, 141070, Russian Federation*, dmitriy.zarubin@rsce.ru
[b] *S.P. Korolev Rocket and Space Corporation Energia, 4A Lenin Street, Korolev, Moscow area, 141070, Russian Federation*, nikolay.sevastiyanov@rsce.ru
[c] *S.P. Korolev Rocket and Space Corporation Energia, 4A Lenin Street, Korolev, Moscow area, 141070, Russian Federation*, eugeny.mikrin@rsce.ru
[d] *Department of long-term Moon exploration program development, S.P. Korolev Rocket and Space Corporation Energia, 4A Lenin Street, Korolev, Moscow area, 141070, Russian Federation*, rushan.beglov@rsce.ru
[e] *Department of business development, S.P. Korolev Rocket and Space Corporation Energia, 4A Lenin Street, Korolev, Moscow area, 141070, Russian Federation*, yury.makushenko@rsce.ru
* Corresponding Author

Abstract

Today there are a lot of discussions concerning Lunar Orbital Platform development and its role in support of deep space exploration. The long-standing experience of the ISS program has demonstrated undeniable advantages of international cooperation. It was mostly fundamental organizational and engineering concept that made such Program a success. The ISS experience should become a foundation for an advanced international Lunar Orbital Platform Program that can unite partners in deep space exploration despite their differences in some of the objectives and make their cooperation mutually beneficial.

This report presents concept of Segment for Lunar Orbital Platform. Segment's primary goal is support and provision of lunar surface missions.

Key words: Cis-lunar platform, Segment for support of the Moon exploration, Cis-lunar orbit, ISS lessons

Acronyms/Abbreviations

CMP – Cis-lunar Man-tended Platform
CTV – Crewed Transportation Vehicle
EVA – Extra Vehicular Activities
GER3 – Third edition Global Exploration Roadmap
GNC – Guidance, Navigation and Control System
HLO – High Lunar Orbit
ISECG – International Space Exploration Coordination Group
ISRU – In-Situ Resource Utilization
ISS - International Space Station
LEO – Low Earth Orbit
LLO – Low Lunar Orbit
LV – Launch Vehicle
Mir OC – Mir Orbital Complex
MPM – Multipurpose (interface) Module
NRHO – Near Rectilinear Halo-Orbit
SM – Service Module

1. Introduction

Third edition of the Global Exploration Roadmap (GER3) [1] was published in 2018. It was developed by 14 space agencies, members of International Space Exploration Coordination Group (ISECG).

Under review is an opportunity to deploy the multifunctional man-tended platform in the next decade, which allows the subsequent and joint step-by-step testing of the deep space flight technologies alongside exploration of Moon, asteroids, Mars and other Solar system objects. The platform resources and its joint operation can support the beyond Low Earth Orbit (LEO) international and national programs. Combining the technological and economic capabilities of each partner, as ISS experience has proved, to reinforce program reliability and safety as synergy of technical and programmatic redundancy.

Moon is a priority for many space agencies. Return to the Moon today implies crew and robotic access to various points of lunar surface, development of man-tended lunar base, where expedition crews will perform long-term activities. It is expected to explore the most promising lunar areas, for in-situ resource utilization (ISRU) and resource delivery from Moon surface. Effective crew and cargo transportation systems are required to accomplish these tasks.

The subjects of this report are the Moon exploration program decisions, international cis-lunar man-tended (transit) platform (CMP) and its segment configuration for support and provisions of the Moon exploration.

2. Moon exploration programs

Leading space agencies are under transition stage from the theoretical and preparation activities to organization of design and launch implementation. The landmark decisions are important at this phase, like in 1964, when Sergey Korolev made the following resolution “Moon landing shall be designed for fairly hard soil…”

There are 3 key decisions areas.

2.1. Moon mission schemes

The basis is that Moon surface missions require crew transit. Crew transits from transportation vehicle to the “lunar” vehicle, which lands to the Moon surface and then return back to the first (transportation) vehicle, which is waiting on the orbit to return crew to Earth. In summary, we have 3 basic options (see Fig. 1):

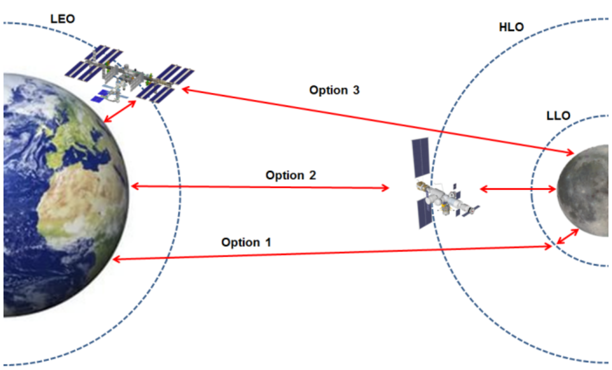

Fig. 1 Basic schemes of lunar-surface missions.

Each option has its benefits, which allow broad discussions, based on their comparison. An unsuccessful choice can result in program schedule shift to the right. It is necessary to match these options with program objectives and with technical capabilities, to determine program timing and feasibility.

2.1.1 Option 1: Earth – Low Lunar Orbit (LLO) – Moon

This option, without use of a lunar orbital station, was applied for Apollo program and characterizes by relative simplicity because it contains the transportation system elements only [2].

This option disadvantages are associated with high requirements imposed on the crewed vehicle Vx margins to enter the cis-lunar orbit and to exit from the orbit when returning to Earth (not less than 1800 m/sec or use of additional deceleration module for braking impulse for cis-lunar orbit entry).

The LLO as an orbit for man-tended (transit) platform has been reviewed in documents [3] and [4]. It is concluded that such an orbit has significant constrains. If no CMP is available, there are, at least, 2 additional constrains:

A. No reasonable options for reusable elements of lunar vehicles.

B. Mission duration is limited by vehicle capabilities in terms of autonomous flight duration.

Option can be used for initial demonstration in the “excursion” mode, but it will not provide required level of transportation system functions for exploration stage.

2.1.2 Option 2: Earth – CMP – Moon

The CMP utilization to accommodate transportation system elements and for crew transfer is the direct analogy to the ISS vehicle accommodation and missions rotation today.

Key point here is an orbit selection, which consists of two tasks:

A. Mitigation of the platform requirements (radio visibility, orbit maintenance, thermal load and etc.) [3].

B. The allocation of total Vx consumption for Moon surface mission shall be optimized between transportation vehicle and Lunar Lander. The consumptions for entry (braking nearby Moon) and return to Earth shall not exceed the manned vehicle capabilities (up to 1200 m/sec). Therefore, the entry and return consumptions could be maximum ones within the vehicle capabilities to reduce requirements, imposed on the Lunar Lander Vx margin and operations.

Recalling main advantages of this option, reviewed in the documents [4] and [5]:

- The Moon exploration tasks are accomplished “step-by-step” (the tasks to test transportation systems and the Moon landing are performed separately);
- The orbits are used, where the Vx consumptions to brake near the Moon (entry to circumlunar orbit) and return to Earth are equal to 900-1200 m/sec, that is within the Vx margin capabilities of the manned vehicles, being developed today;
- Requirements for launch vehicle capacity are at least 15% less in comparison to LLO; among others this allows reviewing the heavy and medium class LV application, supplied by different launch providers;
- CMP provides options for reusable systems application even at early stages of the Moon exploration;
- During the CMP missions as well as the Moon surface missions, crewed vehicles are stored as part of CMP and they don’t consume autonomous flight resources (similar to Soyuz vehicles, providing the ISS crew rotation), and don’t constrain the mission duration.

The required Vx margin for Lunar Lander transfer from high orbits to Moon surface is up to 2850 m/sec that is up to 750 m/sec higher than for LLO (2100 m/sec). This results in additional propellant consumption to descent from high orbit. The disadvantage of high orbits application for descent on lunar surface is recovered by the entry consumptions (braking nearby Moon), which are equal to 450 m/sec for NRHO instead of 900 m/sec for LLO. The calculations show that consumption for High polar lunar orbit (HLO, H ~ 10000 km) is 600 m/sec, and in case of the gravitational-spherical transfer it is reduced up to 335 m/sec [6].

2.1.3 Option 3: Earth – ISS orbit – Moon Surface

Opposed to previous option, covering crew transfer to lunar vehicle on the Cis-lunar orbits, crew is transfer on LEO, so called the «direct to Moon option» [7]. According to the option, the entirely fueled lunar vehicle is delivered to Moon from LEO by separable upper stage. In this case it is foreseen to have the direct return of lunar vehicle, ascending from the Moon surface to LEO.

The propellant consumptions are incomparably higher than options 1 and 2, for the vehicle launch and transfer from the lunar surface to LEO. This necessitates the Moon-produced propellant [7], [2]. Another solution suggests application of aerodynamic deceleration during reentry or refueling at interim near - Earth orbit [8].

In addition to transfer, it is foreseen to refuel the lunar complex elements on LEO to provide reusability. Therefore, the options of the LEO to Moon missions are actually connected, like in options 1 and 2, with orbital platform or station (ISS or its analog, for example).

The current lack of the lunar surface–produced propellant technologies and the space refueling by the cryogenic components as well as flight-proven spacecraft, which can use aerodynamic braking, put off possibility for use this option until further technological developments.

2.1.4 The hybrid options

Other schemes, based on the 3 main options combinations, can also be suggested. So, the option of the Moon surface missions with the ISS and CMP simultaneous application is reviewed in documents [5] and [8].

2.2. Orbit for the CMP – the Lunar "Spaceport" deployment

NRHO as an option for CMP deployment, having a number of advantages, is being broadly discussed:

- relatively low requirements, imposed on Vx margin of manned vehicles (braking nearby Moon) and return to Moon (~ 900 m/sec);
- good radio visibility conditions and Sun-shadow environment;
- no additional CMP Thermal load, as opposed to LLO and etc.

The increasing of Vx consumption to transfer between NRHO and Moon surface is largely compensated by the low energy transfers from LEO.

The CMP location and crew transfer between the manned and lunar vehicles on high altitude orbits is preferable, taking into account options, compared in section 2.1. Let’s define high altitude orbit class as the orbits, where the entry consumptions (braking nearby Moon) and return to Earth don’t exceed 1200 m/sec for the “fast” transfer schemes of crewed vehicles.

Thus, NRHO can be reviewed as basic option for CMP location. With it, NRHO maintenance requires about weekly corrections. The requirement to provide global access to Moon surface from NRHO necessitates increasing of propellant reserves and/or duration of crewed Lunar Lander autonomous flight [9].

In documents [5] and [6] the cis-lunar High polar orbit HLO (altitude ~ 10000 km, period - 1,32 days) is described as an orbit, which has similar advantages to NRHO. The requirements to Vx margin for manned vehicles are acceptable ones (up to 1200 m/sec). However, the HLO characteristics are the following:

- relatively easy orbit maintenance: 2-3 corrections per year;
- relatively easy phasing during return from Moon surface (as for ISS missions).

In the document [9] one of strategies to have global access to Moon surface from NRHO suggests a scenario, according to which Lunar Lander reaches the intermediate circular polar orbit (H=100 km) and awaits for optimal trajectory to land at estimated point. The optimal trajectory is provided by Moon slew relative to the orbital plane by 13,1° per day. The drawback in this case is the increase of the crewed Lunar Lander flight duration that reduces duration of Moon surface expedition. CMP location on HLO matches the above mentioned strategy, however, at this time Lunar Lander and crew are waiting for optimal trajectory while staying onboard CMP without consumption of Lunar Lander resources.

On identifying the high altitude orbits as preferable class to accommodate CMP, and defining main criteria (simplification and cost reduction of CMP operation, the allocation optimization of Vx consumption between crewed and lunar vehicles), it is necessary to draw the light to the following.

Choice of optimal base orbit for CMP is the function from the transportation system applied and geographical location of the launch and Earth landing sites. In addition, the inter-orbital transfer can be made in cis-lunar space, based on relatively low propellant consumption. The considerable number of factors, affecting the orbit optimization, forces us to conclude that choice of exact CMP basic high lunar orbit is still an open issue for further studies.

2.3. Program robustness

The concept of International CMP, developed by the space agencies – ISS program partners, and supported by ISECG participants, allows to propose approaches for appropriate level of redundancy and program robustness.

The basis is the ISS program approaches, which has a proven effectiveness. The main approaches are:

<u>Modular assembly principle.</u>

Allows assigning the station global tasks to its different elements. Potential risks per each separate element do not critically affect the total program success.

<u>Two segment configuration.</u>

Configuration provides dissimilar redundancy of main systems. Availability of two transportation systems became a key point to the program.

<u>International program framework.</u>

Program implies the equality of partners, sharing the rights and responsibilities, based on balance of contributions:

- Multilateral control boards;

- Mechanisms, which provide decision making on consensus basis.

Such principles, specifying the international framework of the program, are a part of the Intergovernmental agreement on ISS, dated 1998 [10]. The «ISS Lessons Learned as applied for exploration» document [11], which approved by ISS Multilateral control board (MCB) in 2009, mostly clarifies the ways to apply the ISS experience and principals for future space exploration programs.

The international cis-lunar man-tended platform is a natural evolution of the ISS program. Participation in CMP development, taking into account the each partner goals in space exploration and maintaining the collaboration principles, is the natural continuation of ISS program participation.

The current technologies, ISS partners industries, existing international regulatory and organizational mechanisms specify to a large extent the CMP feasibility and assembly against the clock.

3. The CMP segment to support Moon exploration

The ISECG participants suggest the GER3 [1], which includes the CMP basic architecture. It is international by nature and <u>multifunctional</u> by operation (Moon, asteroids, Mars) (see Fig. 2).

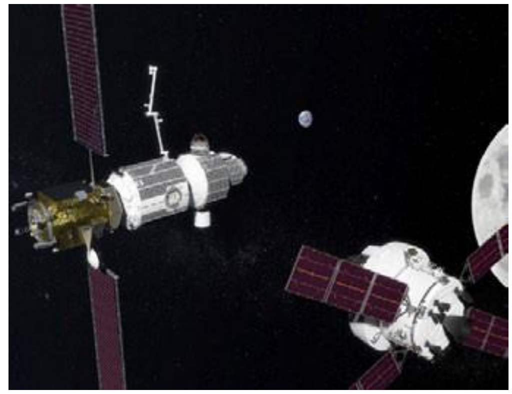

Fig. 2 – Concept of international multifunctional cis-lunar platform [1].

Rationale, specified in section 2 above, as well as CMP involvement in Moon exploration support, have significant influence on its configuration.

Taking into consideration ISS experience and objectives differences at various operational stages [5], it is possible to combine the CMP systems, designed to support the Moon exploration, in one segment. Let's review the main requirements, structure, functions and conceptual configuration of segment to support and supply the Moon surface missions as part of CMP and its elements.

3.1. The segment functions

The main functions are the following ones:

- The lunar architecture element accommodation for Moon surface missions (Lunar Lander elements, vehicle-tanker for refueling of re-usable lander elements and etc.), crewed and cargo re-supply vehicles;

- Refueling support of Lunar Lander re-usable elements;

- The Lunar Lander checks and maintenance before missions (including visual inspection of external surface) considering its potential assembly as part of CMP and the re-usable element application.

These functions can be performed if CMP is outfitted with the specialized elements. This, in its turn, will have negative impact on the platform resource balance, power and controllability level. It is required to keep in mind the CMP growing importance as a transportation hub, providing access to Moon surface, and associated reliability requirements.

The additional segment functions are the following:

- Accommodation of additional executive systems to control the platform motion (thrusters, gyros);

- The main system redundancy of CMP initial architecture.

3.2. The segment structure

3.2.1. The general architecture

The main conditions:

- Sequence to integrate the new elements into CMP should be harmonized with tasks of Moon exploration for specific time period;
- The mass and dimensions of modules should not prevent from their delivery by available LV and Upper Stages;
- The integration of the segment modules should not worsen the CMP controllability, the approach zones for vehicles, solar array shadowing and etc.

These constrains force us to review the CMP segment configuration (to support and supply the Moon surface missions), consisting of 2 modules:

- The multipurpose (interface) module;
- The service module.

3.2.2. Multipurpose (interface) module (MPM)

This module is the first one for CMP segment to support Moon exploration, which provides the following:

- approach and docking of the IP manned and cargo vehicles;
- nominal EVA capability;
- pipelines from tanker-vehicle, docked to one of the module ports, to refuel Lunar Lander re-usable elements.

Based on designation and general configuration MPM consists of three compartments:

- airlock for EVAs;
- transfer compartment as airlock redundancy and as additional space to accommodate service and scientific hardware;
- docking compartment to host vehicles.

Conceptual configuration of module, subject to potential unification with Russian Node, MRM-1 and 2 (see Fig. 3).

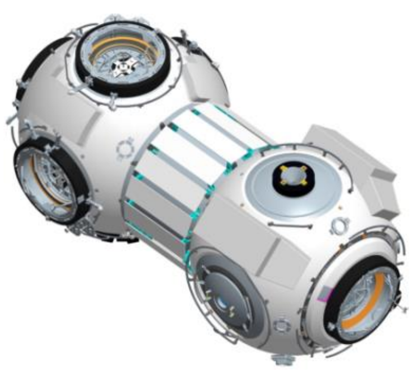

Fig. 3 – The conceptual configuration of multipurpose (interface) module as part of CMP segment for support and provision of Lunar surface missions.

MPM docking compartment has to be located along the CMP longitudinal axis. The MPM transfer compartment and airlock are side-located relative to longitudinal axis. Therefore, airlock does not impede the crew path between CMP modules and vehicles.

Number of docking ports depends on number of simultaneously docked vehicles. Three radial docking ports are assumed to host crewed transportation vehicle (CTV) «Orel» (Eagle), Lunar Lander and Tanker-vehicle (see Fig. 4).

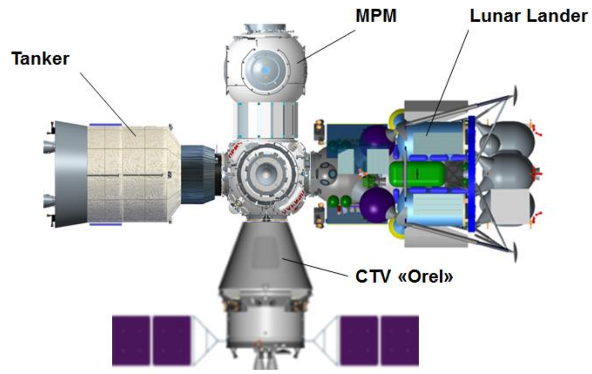

Fig. 4. - Multipurpose module hosting crewed transportation vehicle (CTV) «Orel» (Eagle), Lunar Lander and Tanker-vehicle.

For docking assemblies it is assumed to install the hydraulic connectors, mated by the transit refueling pipelines (see Fig. 5). The technical solutions and fixture to provide refueling aboard the station has been validated on ISS Russian segment.

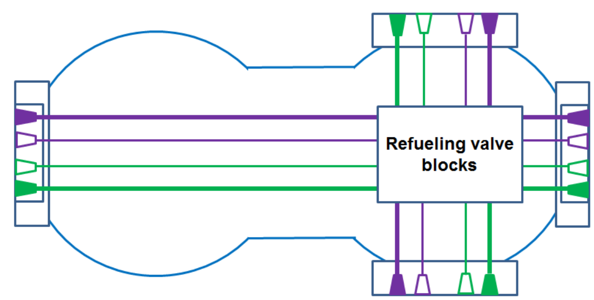

Fig. 5 – Layout of main refueling pipelines

MPM designing analysis shows the ~9 m.t. module mass. MPM integration into CMP does not significantly impact on the controllability and the resource balance of CMP basic configuration.

3.2.3. Service module (SM)

SM provides the following:

- Accommodation of equipment to perform monitoring and functioning check of the manned, cargo and lunar vehicles, when docked to CMP;
- Additional pressurized volume, crew staying;

- control of CMP motion (due to increasing of CMP mass-inertia properties, caused by segment integration and Lunar Lander element accommodation) within single guidance, navigation and control system (GNC), IP modules including;

- Redundancy (dissimilar redundancy) of CMP main systems.

SM is comprised of 2 compartments:

- Pressurized compartment, where the main service systems and utilization hardware are located;

- Unpressurized compartment which includes propulsion system.

Dimensions of pressurized compartment can be defined, based on total volume of CMP module to be used for crew staying.

The reviewed module layout assumes a pass-through for crew to have access to crewed or cargo vehicle, docked to the SM equipment bay port (tunnel inside equipment bay).

As GNC actuators, the liquid – fueled engines and gyro are being reviewed. The same liquid – fueled engines can be used for CMP re-boost.

The propellant system tanks are capable to be re-fueled by cargo vehicle, docked to any segment port. Refueling can be also performed by tanker (for example, usage of Lunar Lander residual propellant after its element fuel loading).

The conceptual module configuration, based on its unification with ISS RS SPM, is shown on Fig. 6.

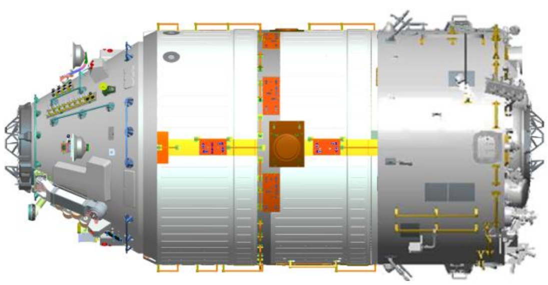

Fig. 6 – The CMP SM conceptual configuration as part of segment for support and provision of Lunar surface missions.

The SM designing analysis shows ~12 m.t. module mass.

3.2.4. CMP segment

The conceptual CMP segment configuration for support the Moon surface missions has been studied based on the ISS background (see Fig. 7).

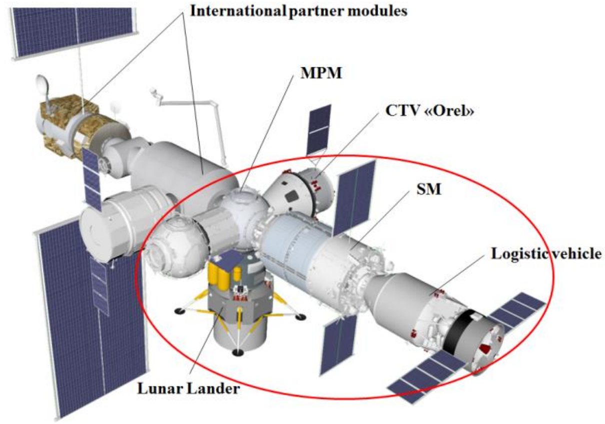

Fig. 7 – The conceptual CMP segment configuration for support and provision of Lunar surface missions.

4. Conclusion

In order to implement the Moon surface missions, three main options should be reviewed, each of them is quite feasible.

The option, covering the crew change of vehicles (from crew transportation vehicle to lunar vehicle on LLO), has already been proven by Apollo program and can find a use for the first demo missions. With that said, this option cannot be justified for the Moon exploration program.

Option of a direct to Moon flight, with crew transfer on LEO (for instance, at ISS), is a matter of long-run prospect.

Option to have man-tended platform on one of the high lunar orbits is the timely and rational one. The option provides the following:

- Subsequent accomplishment of Moon exploration tasks: validation of the Moon flights and the lunar surface landing systems;

- Optimal allocation capability for Vx consumptions (for crewed and lunar vehicles);

- Prospect of the re-usable system application;

- Removal of the duration constrains for the Moon surface missions, caused by autonomous flight resources of the manned vehicles.

The exact CMP basic high lunar orbit is still to be further studied.

CMP basic architecture studies (GER3) for the Moon exploration have resulted in the following conclusions: CMP is required to be outfitted with the specialized modules.

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