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Human Space Exploration architecture study in TAS-I

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Abstract. The international space exploration plans foresee in the next decades multiple robotic and human missions to Moon, Mars and asteroids. The US Space Exploration program addresses the objective "to explore space and extend a human presence across the Solar System". Main steps include the completion of the International Space Station and its utilization in support of space exploration goals, "as the launching point for missions beyond the Low Earth Orbit". Along a parallel matching path, Europe has developed a roadmap for exploration Aurora and has supported design activities on combined Moon-Mars Exploration Architectures. Thales Alenia Space Italia has been involved in the major European activities related to exploration and it is currently analyzing the different exploration scenarios considered by the major Space Agencies with the objective to identify an international reference scenario for exploration taking into account the need to balance collaboration at international level due to the highly demanding nature of planetary exploration missions, and the development of autonomous key capabilities considered of strategic importance.

1. Introduction

The complex and demanding nature of Moon and Mars exploration missions and the current critical economical and political international scene impose a careful analysis of the possible architecture options to meet specific mission scenarios objectives so as to identify the required building blocks and derive the strategic European contributions. Given its strong political and financial commitment, the global space exploration picture is driven by the US space exploration vision, with a parallel strong European interest to build-up from existing technological capabilities and competitive assets and to develop a robust role as appealing partner, and a growing support at international level. The current approach is not focus to a specific priority destination rather to the development of the enabling technologies for planetary exploration. Comparing the current exploration plans at international level for both Moon and Mars exploration, it appears evident that each country is moving through a phased approach where the initial robotic missions are typically performed with:

- orbiter: to acquire information and knowledge about the planet characteristics and resources
- lander: to validate the capability to reach the planet surface
- rover: to reach and explore sites of particular interest

This approach results in a repetition of missions with similar features, whose value is justified by the need to develop and master the key capabilities required to perform planetary exploration missions. Once these basic capabilities are acquired, it will be mandatory to plan for complementary missions, each one contributing to an international exploration plan where the competences and interests of each partners are valued.

2. Human space exploration final destination

The ultimate mission is represented by a human visit to the Mars surface. To achieve this ambitious goal a set of preparatory dedicated missions should be planned to support acquisition of scientific/safety data. The huge effort, both technical and economical, associated to such a mission leads to consider not only the crewed mission itself but also the preparatory campaign as an international endeavor. From this perspective, the various stages of Agencies space programs should address "coordinated"scar provisions (e.g. coherent allocation of technological/development efforts), to support completeness of assets and avoid duplication of efforts/costs, while providing redundant functional legs.

3. International Space Station utilization

The International Space Station utilization and composition should be enhanced to sustain scientific Earth-oriented objectives and support the acquisition of long-term exploration-oriented capabilities (Fig. 1). In particular, the presently available ISS architecture could be progressively open to accommodate/rotate additional scientific payloads and capabilities (with the support of scientific community and Agencies). This can be achieved by performing a dedicated investigation focused on possible ISS engagement to support demonstration of technologies for long duration exploration missions (telemedicine, e-health, psychological and stress countermeasures, rapid prototyping and on-site production capabilities) or in view of post-ISS evolution (e.g. inflatable modules). Moreover, wide attention should be given to develop and test on-orbit robotic solutions which might substantially support both the post-ISS evolution and the exploration missions:

- Tele-operated robotic devices directly controlled by crew to execute external or internal operations
- Crew collaborative robotic devices to support crew tasks (external or internal) with a sliding level of autonomy. This could be preparatory to design robotic assistants for astronauts engaged in exploration missions.

The operation and growth of the ISS could take into account possible extended utilization of individual modules as prototype vehicles to conduct demonstrations of outer exploration missions.

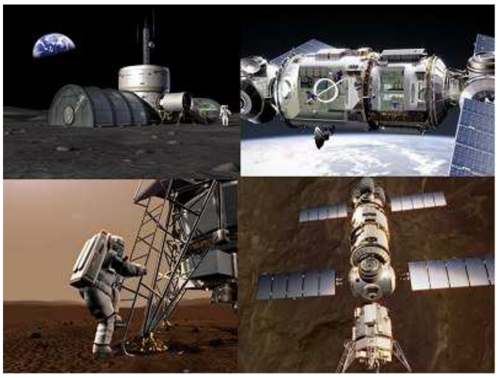

Fig. 1. From ISS to Moon and Mars (ESA)

4. Post-ISS human operations in LEO

A post-ISS infrastructure should be designed to serve as a LEO facility with enhanced habitability properties and supporting capabilities for exploration missions. In particular, the architecture of a new LEO infrastructure could include new types of elements with enhanced capabilities to support comfortable and safe human life (radiation, meteoroids protections), high degree of resources regeneration, and self sustainable operations (energy). Moreover, dedicated parts of the infrastructure should be designed to support exploration missions operations like crew training, assembly, integration, check-out, and maintenance of exploration vehicles, and vehicle flight operations. The architecture should include:

- dedicated decks with robotic devices to implement integration and servicing operations
- storage capabilities for resources and fuel
- "on-orbit"mission control centers and crew headquarters
- quarantine / medical quarters

5. Advanced human transportation system

Intensive utilization of LEO infrastructure and possible extension of human categories access should address specific criteria for the design and operations of transportation systems:

- Separation of crew and cargo transportation systems (to limit the cost of cargo transfer, compared to the safety implications of crew transportation)
- Crew vehicles with advanced flight capabilities (cross range, maneuverability, limited accelerations) and high level of safety
- Minimization of operations costs (adoption of the reusability criteria both for the reentry and the propulsive constituents, including the adoption of advanced "vehicle health management systems").

The relevance of the development costs makes even more important the assessment and the choices related to the launcher. This subject is a key factor which should be evaluated at international level, taking into account not only LEO targets, but also the needs associated to the exploration missions.

6. Near/medium-term Moon exploration

The near/medium-term exploration missions might be oriented to acquire key information and technological experience related to lunar exploration (Fig. 2). Choices about long-term evolution should be kept in "suspend mode"pending an integrated assessment focused on really attainable and accountable return. So, different types of missions might be planned in the next years:

- to get scientific data about Moon characteristics and properties
- to get feedbacks / confirmations about exclusive opportunities of science "from the Moon"
- to develop technologies enabling reliable access to lunar surface (e.g. precision landing, obstacle avoidance, throttable propulsion, power generation supporting mobile systems, mobility implementations to transport cargo and/or crew, ISRU capabilities)
- to identify and demonstrate robotic solutions supporting surface operations.

A global evaluation shall than be conducted to establish the attractiveness and sustainability to a next phase of exploration and exploitation of the Moon supported by humans. The conclusions of this assessment should be supported by corresponding investigations related to resources utilization on Earth, like the potential use of Helium-3 in the energy sector. A positive feedback in this sense could heavily steer and condition the priorities of the so called "exploration flexible path", and might become a key factor for the selection of the required exploration plans.

7. Mars human missions preparatory steps

Considering the huge effort to be put in place and the extreme complexity associated to a Mars human mission, preparatory steps based on incremental acquisition of capabilities are considered mandatory. The necessity to avoid duplication of efforts/costs should motivate the creation of an International organization addressing not only the potential opportunities of cooperation in performing preparatory missions but actually the consistency of the efforts. In this context Exomars and Mars Sample Return are considered cornerstone programs. Technological developments in different fields

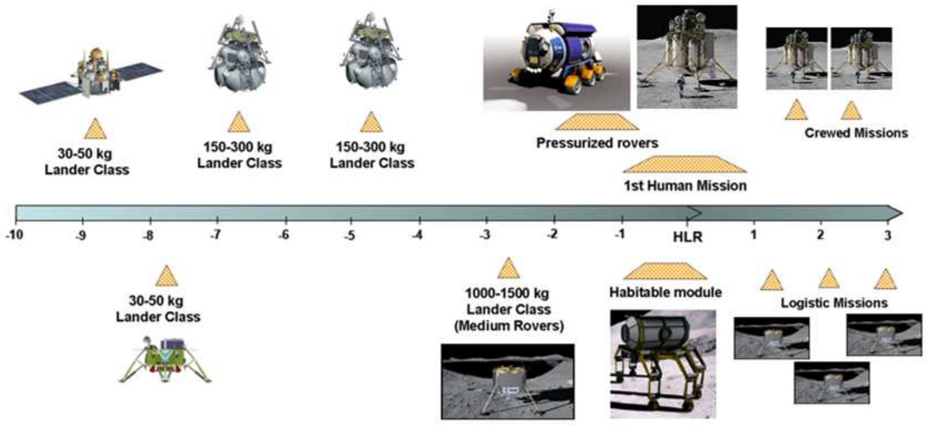

Fig. 2. ISECG International Lunar Exploration Scenario

are mandatory: planetary protection, Mars specific ISRU issues, propulsion capabilities, energy generation, storage and management. Moreover, those related to human missions could receive inputs and support by the incremental steps of the "Flexible Path"approach, with specific commonalities associated to possible missions to NEOs.

8. Flexible path

A "Flexible Path"approach should be established in the short-medium term period, in order to keep open decisions and steps towards the final destination, maximizing the potential re-utilization of results derived from intermediate actions and investments. This approach requires a careful anticipated analysis of technological needs and future integrated applications to clearly identify basic essential issues whose solutions could be directly adopted for utilization in whatever scenario evolution. In other terms, the ambitious objective would be to identify a number of technologies / products which could constitute a basic set of assets to compose the core solutions for the future missions in a relative restricted number of exploration scenarios. Strategic decisions may be therefore implemented in the near/medium term concerning:

– Launch capabilities and propulsion technologies
– Assembly and servicing of elements in orbital mission nodes, including automatic rendezvous of modules, fuel storage and management.
– Techniques of approach and "landing / docking "for different categories of targets (orbital bodies with limited or no gravity like NEOs, planetary surfaces with significant gravity, presence of atmosphere, vacuum, spinning properties).
– Development of pressurized elements to be utilized as pre-defined building modules for composed applications (command and control modules for landers or rovers, habitable elements, regenerative life support elements, laboratories, robotic devices).

9. Deep Space missions

In the frame of Deep Space mission scenarios, the exploration of Near Earth Objects and asteroids presents technological, scientific and planetary health interests. From a technological viewpoint, in fact, the requirements imposed by a mission to NEOs, with a duration not shorter than 6 months, could represent an incremental test bench of capabilities as addressed by the "Flexible Path"approach. An enabling technology to be developed and validated could be the final approaching and docking with a non-collaborative target. Moreover, a human mission to a Near Earth Object could be regarded as a representative demo-mission of a future human mission to Mars. From a scientific point of view, a NEO mission can provide possible exobiology feedbacks (trace of life, origin of universe) and potential resources exploitation. A political rationale supporting a NEO mission might originate from the increasing attention and interest at developing overall measures of Earth protection against the threat of a collision with a large celestial body. Techniques of various types could be subject of coordinated study and development, depending on the characteristics of the NEOs themselves, the expected available time for reaction from the notification, the rendezvous opportunity windows.

10. Potential European contributions

In developing its strategy for exploration, Europe shall build upon the solid expertise acquired with missions like Mars Express, Rosetta and Smart-1, and carry on with robotic missions to meet the scientific objectives indicated by the science community and to validate the key capabilities and technologies required to reach and explore a planet surface landing/ascent, surface mobility, In-Situ Resources Utilization, navigation and telecommunication, radiation protection. With this regard, the development of a logistic Lander is regarded as a high priority element to be developed by Europe because it would enable implementation of European autonomous robotic missions and participation in international human exploration missions. Building upon the robust heritage acquired by Europe in contributing to the ISS development, a LEO post-ISS infrastructure development would respond to the need to continue fundamental and applied research in microgravity conditions at the end of the ISS operative life, also permitting the development of new capabilities for sustaining human presence in space. Key elements like the cargo lunar lander, the surface habitat, and the pressurized rover could be regarded as European strategic contributions to the international human exploration of Moon and Mars (Fig. 3). Moreover, new alliances and partnerships might be developed by Europe for the development of commercial crew transportation system, that might have a high strategic value in offering a redundant capability for such a critical functions w.r.t. what is available or in development at international level.

11. Conclusion

The global space exploration programme is well positioned to prepare the framing conditions for the continuous development of a European space industry and its capabilities. It is necessary to set up a platform at political level enabling potential international partners to:

- confront their expectations and needs
- continue their discussions on multiple exploration scenarios
- identify collaboration schemes and complementarities leading to a global interdependence between the partners, rather than a juxtaposition of initiatives from independent actors

From an industrial view point, space exploration will stimulate technological development activities, industrial innovation, and economic growth, and it will expose the European industry to a significant competitiveness at international level. A European space exploration strategy is mandatory to clearly outline the specific European space exploration priorities and to develop a coordinated network of international collaboration. A key priority at European level should be given to the extension of the utilization of the ISS beyond 2020 with the threefold goal to increase its benefits, enhance its visibility and decrease its operational cost. A European technology program should be set up, identifying and developing key technologies for Europe to bring into the international partnership, including and in parallel with Europes participation in a robust robotic exploration program. It is important and necessary to resolve the issue of transport to and from LEO, because of a shortage

Fig. 3. Moon Surface Infrastructure (Thales Alenia Space - Italia)

of transport systems and the lack of a common transportation policy between partners, which could jeopardize the optimal utilization of space infrastructures in LEO.

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