Operations and Logistics

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Abstract.

The implementation of a "Moon Base" is a great Operational and Logistic Challenge, whose natural starting point is the Logistic and Operations experience of the International Space Station.
The paper presents an overview of the general topics of this experience, in particular those identified to be applicable to the Moon Base implementation and maintenance, with particular attention to methodologies of proven effectiveness..
It also outlines the possible operational approaches that make direct use of the ISS.
Finally, it shows how the Italian Aerospace industries have developed a significant "competitive position" for what concerns the "Integrated Logistic Support" to manned space infrastructures, through their participation to the ISS and their tight relationship with NASA and the Major Aerospace U.S. Companies, that, together with other complementary expertise achieved at national level (e.g. in the military field), fits very well with the needs and perspectives of a future joint effort.

1 Introduction

Despite a clear and definitive overall scenario of the "Moon Base" is not yet identified, it is in any case possible to trace basic common features, around which to highlight some of the most intriguing challenges posed by the provision of the logistics to a manned outpost or base on the Moon.

- Assembly in orbit of specialized Pressurized Logistic Modules.
- Utilization of the Pressurized Logistics Modules as Storage Elements at the Moon Base.
- Standardization and Hardware Modularity, particularly of On-Board Replaceable Units.
- Implementation of maintenance and repair capabilities at the Moon Base.
- Need for strong International Co-operation.
- Clear definition of the responsibilities on the basis of competitive assessments.

If to face up to challenges is an ingredient (may be the most important) of the "*recipe*" for technical progress, other ingredients are the technical "achievements" obtained up to the previous step of advancement and the "experience" gained through the exploitation and operations of the technologies and methodologies available. Indeed for what concern the "Moon Base" these two ingredients exist and, as made evident by the above list, the progress step from which to move on is the "Operations and Logistics of the ISS".

Taking into account the scope of the Conference, to be a forum where to testimony both the understanding of the "challenges" and the availability of specific capabilities within the Italian industries, in the following this paper will place the emphasis on those aspects for which, it is believed, Italy could play a significant role as a partner of the great international vision of a manned space exploration.

2 The International Space Station and the MPLM System as a "Learning Ground" for the Space Exploration's Logistics

The logistics and operations definition of the "Moon Base" must start from the basic lessons learned of the ISS (see Ref.2) encompassing all the engineering aspects:

- Programmatic - The necessity of establishing a proper Integrated Logistics Support structure.
- Design - The necessity to develop requirements driving supportability and control life cycle cost.
- Operations - The necessity of extensive planning for operating and maintaining complex on-orbit infrastructure.

adequately elaborated to be tailored to the additional complexities of a manned station on the moon surface including:

- A much longer distance of the manned outpost from the Earth.
- The necessity to guarantee larger decision autonomy to the crew.
- The necessity to guarantee intervention capabilities to the crew concerning off-nominal maintenance.
- The difficulty in assuring a continuous flux of cargos delivering basic supporting elements for the survivability of a large crew.

These additional complexities, in particular, will require the invention, development and implementation of new methodologies and the acquisition of a "culture" shared among all the international partners participating to the moon exploration.

A clear, significant and complete identification of how the new methodologies will have to work is not possible without an honest critical review of what is presently on-going on the International Space Station, taking into account the overall management of the logistics including the international partners contributions, finalized to trace the "global" operational framework of the Integrated Logistics of the Moon Base.

The elaboration of possible solutions conducted at "national" level (intending also Europe as a nation) has the positive effect of stimulating industrial competition for the eventual affirmation of the best tool and methodology only if the operational framework is agreed and accepted by all the partners of the endeavor; if this agreed framework is not elaborated the consequences will be an inefficient money and skills expenditure.

As a first contribution to the future multi-partner discussion, it is briefly traced in the following the basic operational aspects and "way to proceed" of the NASA-ASI partnership for an efficient and efficacious management of the main logistics element of the ISS, the Multi Purpose logistic Module, MPLM.

It is worthwhile noting that the International American Astronautical Society has selected MPLM as study case for the next forthcoming seminar "Case Studies in International Cooperation: Lessons for Exploration", to be held in Washington at the beginning of June 2005.

The Multi Purpose Logistic Module, MPLM.

MPLM is a key element of ISS Logistics, being the transfer module, carried inside the Space Shuttle, which gives the maximum upload and download capability. In addition, once the NODE2 is attached to the Space Station, it will be possible to perform the so-called MPLM active mission, equipped with the refrigerator MELFI (developed by ESA), unique possibility of multi-purpose transportation in such controlled environment.

Alenia Spazio has developed the Multi Purpose Logistic Module under contract of the Italian Space Agency, ASI, following the related Memorandum of Understanding between ASI and NASA.

ASI has delivered to NASA three MPLM units:

- *MPLM FM-1 (Leonardo), August '98.*
- *MPLM FM-2 (Raffaello), August '99.*
- *MPLM FM-3 (Donatello), February '01.*

with the agreement of providing the Sustaining Engineering and the Logistic Support, as described in the MOU and detailed, in particular, by Ref.10 and 11.

Five MPLM missions flown up to now: 5A.1 (March 2001), 6A (April 2001), 7A.1 (August 2001), UF1 (Dec 2001) and UF2 (June 2002).

In the upcoming mission LF-1, STS 114 - Return to Flight, now schedued for July 2005, the Shuttle Discovery will carry MPLM Raffaello.

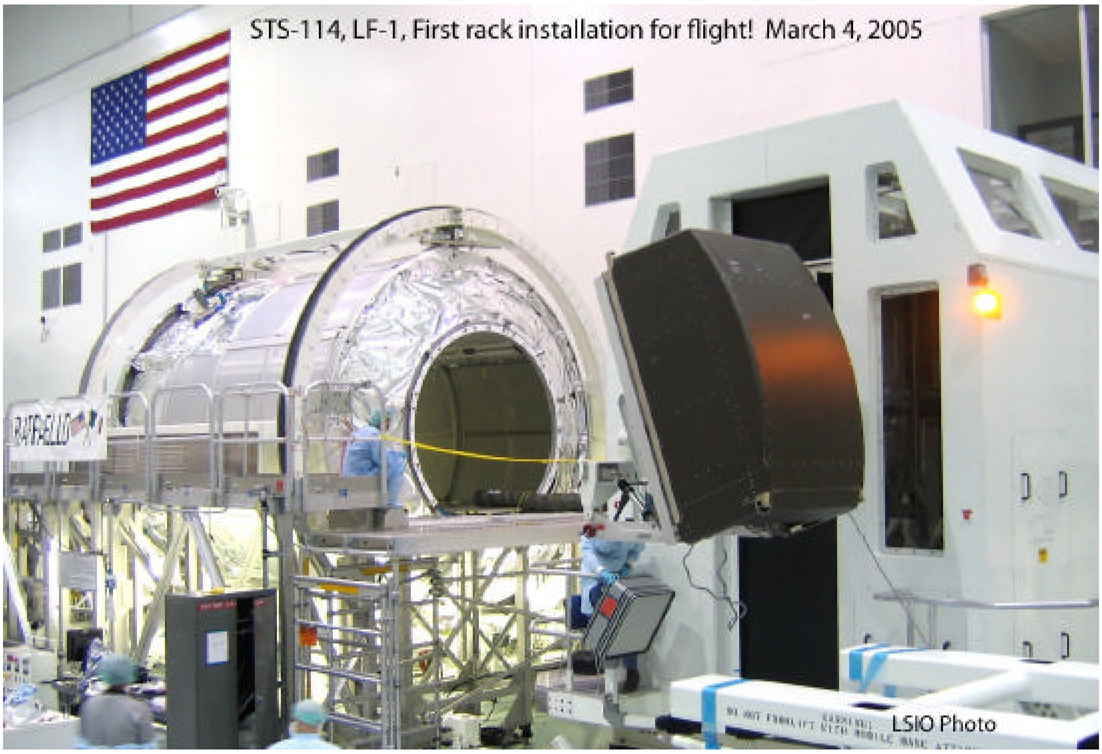


Fig.2.1 Integration of MPLM Raffaello at Kennedy Space Center

Raffaello will transport four Resupply Stowage Racks (RSRs), seven Resupply Stowage Platforms (RSPs) and a Standard PL Rack (HRF-2).
Various cargo typologies will be delivered: Spare items (CheCS, ECLSS, EPS), Crew Provisions, clothing and Care Packages, EVA Equipment, equipments to be replaced (GPS Antenna, PCS, MISSE, Photo TV items), Russian Hardware.

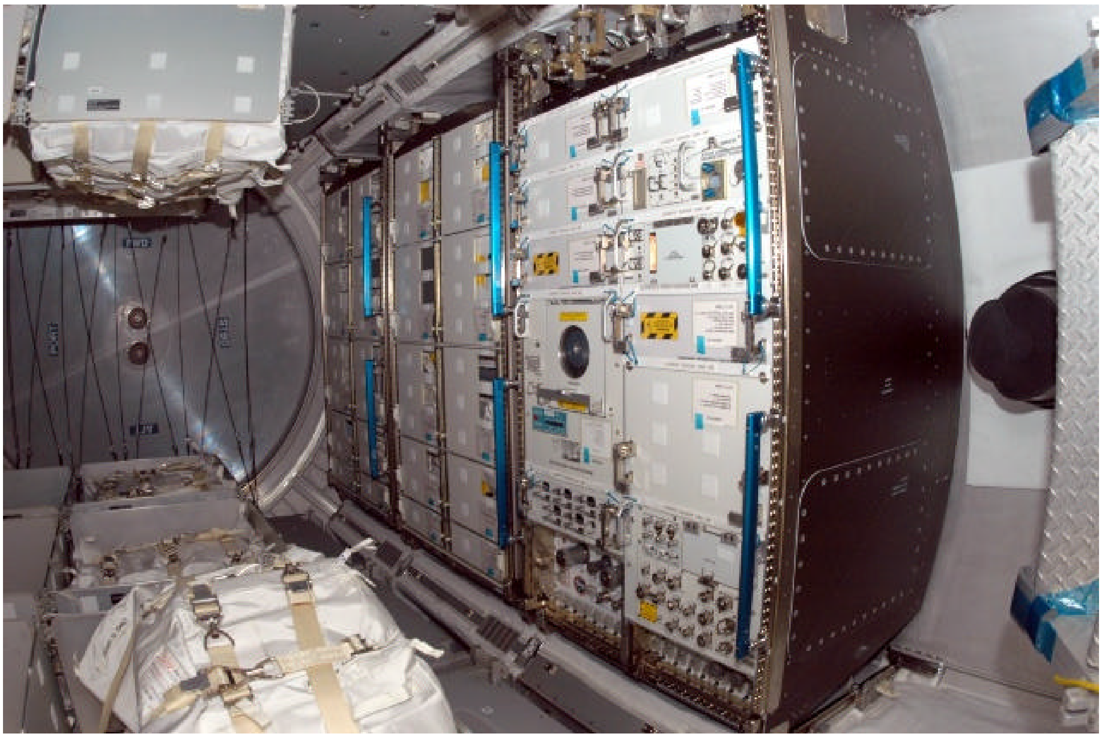


Fig.2.2 MPLM Raffaello outfitted.

The MPLM Raffaello cargo can be quantified as:
80 Cargo Transfer Bag Equivalents (CTBEs) delivered (~1000 Kg)
HRF-2 delivered to US Lab (~750 Kg)
142 CTBEs return (~2500 Kg).

The total delivered and returned cargo masses are:
Ø Ascent: MPLM Tare (4400 Kg) + Cargo (3840 Kg) = 8240 Kg
Ø Descent: MPLM Tare (4400 Kg) + Cargo (4560 Kg) = 8960 Kg

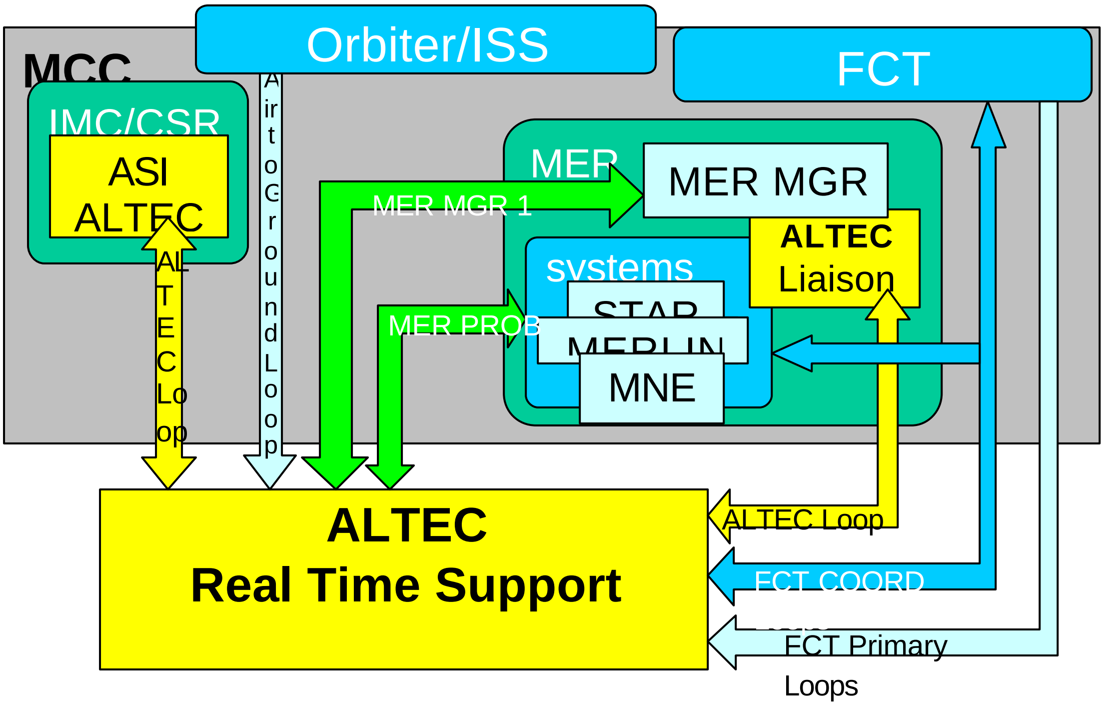
Remarkable Methodological Aspects of the MPLM Program

The activities of Sustaining Engineering and Logistic Support to MPLM are responsibility of ALTEC (Advanced Logistics and Technology Engineering Center) S.p.A., private/public partnership of Alenia Spazio, ASI and Local Entities of Turin Region, created to provide a broad range of services in the field of the ISS Operations & Utilization support.
ALTEC provides the requested support not only in direct technical continuity and close synergy with Alenia Spazio, but following a remarkable organizational methodology of full integration with NASA and NASA Contractors teams.

Two examples of the integrated approach established for the Operations and Logistic support are hereafter briefly summarized:

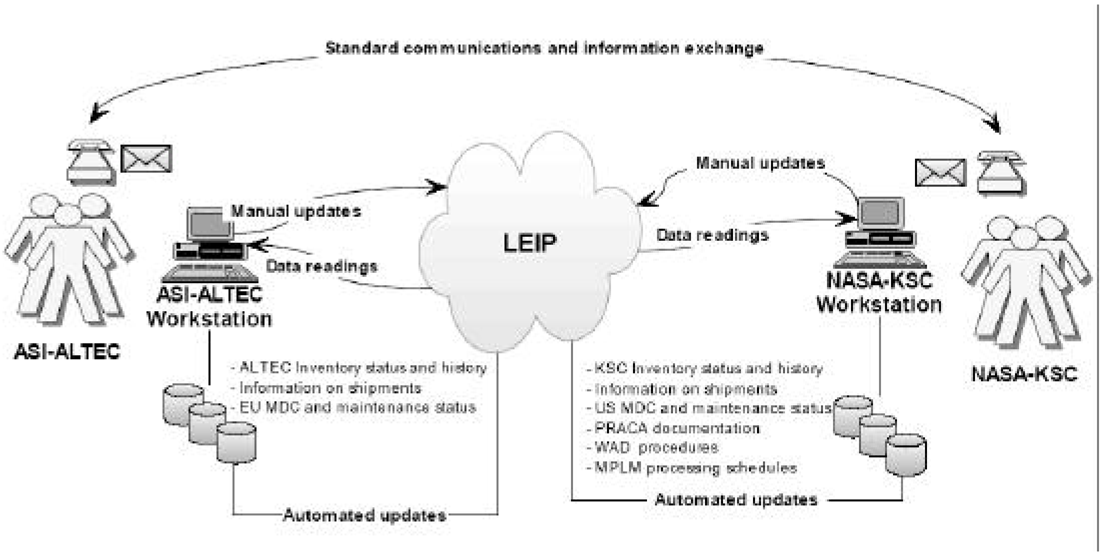
- Real Time Support of MPLM Missions:

The Real Time Engineering Support to the MPLM missions is provided by the ALTEC Team, supported by Alenia Spazio, by means of the ALTEC Mission Support Centre; the centre has a continuous dedicated connection to NASA Johnson Space Center via ASINET, operative network established by ASI (and managed by Telespazio), that gives access to the ISS flight telemetry, imagery and all relevant voice loops (17 in total). The Centre, certified by NASA for this purpose, allows the full integration of the team located in Torino with the activities of the Mission Control Center and the Mission Evaluation Room.



- Logistics Support to MPLM:

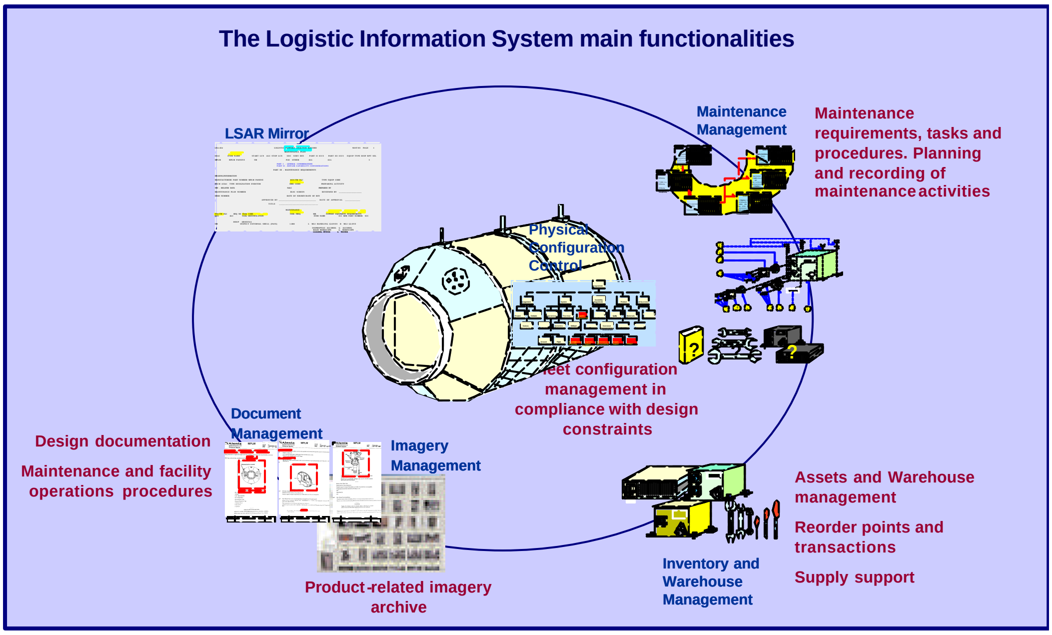
The Logistics Support to MPLM is provided by ALTEC in close coordination with the U.S. counterpart (NASA and NASA Contractor); not only the ALTEC residents at NASA Kennedy Space Center work in a fully integrated manner, but the exchange of information with the ALTEC Logistics Team in Torino takes advantage of the regulated access of both parties to the Logistics Enterprise Information Portal (built up for this purpose by Boeing), as shown by the following scheme.



LEIP	**Logistic Enterprise Information Portal**
MDC	**Maintenance Data Collection**
PRACA	**Problem Report And Corrective Action**
WAD	**Working Authorization Document**

It is also worthwhile noting that, in order to support in an effective manner these bilateral logistic processes, ALTEC has conceived the LIS system, developed with Vitrociset S.p.A. under ASI contract.

The Logistics Information System (LIS) is a web-based information system oriented towards support to activities of Logistics and Maintenance and Engineering Support on complex systems.
The system has been developed as an add-on of Windchill, a PLM (Product Lifecycle Management) developed and marketed by Parametric Technology Corporation (PTC), mostly based on Java 2EE technology and boasting a significant pool of installations in the aerospace industry (Alenia Spazio, Airbus and NASA/JSC are some of the major customers in this field).



3 An Exploration Logistics approach based on the ISS

In an evolutionary approach of the manned exploration of the space the ISS will not be only a source of "lessons" for the separate phase seeing the establishment of a Moon outpost; indeed, the ISS could represent the centre of gravity of the logistics activities supporting the Moon Base.

In the following it is provided a brief description of a potential exploration logistics approach, conceived taking into account the opportunity of a full exploitation of the modular architecture, and growth capabilities of the ISS. These characteristics, together with the complexity of the functions and services managed and provided, allow the ISS to be integrated in a wider scenario, such as Exploration, with initially little or no modifications.

Looking in details how the completely assembled ISS can be focused on the Exploration purposes in the short and long periods, two main roles can be identified:

- The ISS as preparation for the Exploration. A unique test bed in the life support, life science and bioastronautics researches, in the developing and proving new capabilities and systems reliability, as a platform for operational experiences and system exposure to space environment. Significant risks mitigation benefits for the Exploration would derive from this role.
- The ISS as a Spaceport in the Exploration flows providing Orbital Services (e.g. cryogenic propellant management, LEO parking, maintenance, assembly and checkout, safe haven).

The ISS, involved as a spaceport in the Exploration, will be required to deal with new questions and issues of orders of magnitude greater with respect to those of the Apollo program since an "Apollo-style" system for a lunar or Mars missions would guarantee with extremely difficulty the attainment of the current exploration objectives.
As an example, for each one of the multiple manned and unmanned missions required to support the Moon base setup up and exploitation periods, the ISS will be needed to provide support to on orbital assembly and check-out of the pre-integrated components of the future exploration vehicle, needed to act as an on-orbit re-fuelling station (currently this activity is already performed in the ISS with non cryogenic propellants when the Progress vehicle transfers the propellant to the Service Module), and finally needed to support and complete the logistic system needed to guarantee resources, consumables and cargo deliveries to and from the Moon.

In this context it is important to estimate if any major constrains would prevent such ISS role and which could be a rough estimation of the required efforts. A preliminary analysis has been conducted within the lunar mission frame, mainly focused on the mission analysis aspects and on the available launcher missions needed to deliver the elements to the LEO assembly stage. Four different scenarios have been used as test cases:

1. Maximum ISS exploitation. The ISS utilization is envisaged both in the forward and in the returning legs.
2. ISS as a leaving port. The ISS spaceport services are provided only in the forward leg.
3. ISS as a re-entry port. The ISS spaceport services are provided only in the returning leg.
4. No ISS utilization.

Regarding the energetic aspects, the analysis has confirmed that the ISS orbit (inclined 51.6 deg to the equator) is not located in the ideal inclination for space based staging operations. Nevertheless the negative contributions have only minimal impacts on the overall mission economy and do not put in discussion the feasibility of the ISS option. In fact, for example, it is already consolidated and widely accepted the penalty in the order of 6%-8% in the payload mass delivered to the ISS by the available launchers and furthermore, the 51.6 deg of the ISS, as well as any other initial LEO inclination of the departure orbit towards the Moon, impacts launch opportunities and only marginally the energetic aspects. In fact, assuming a maximum inclination change of 30 deg (with apogee radius corresponding to the Moon distance) it is required a Delta V of about 100 m/s and this consideration impacts both 51.6 deg and 28.5 deg departure inclination options according to the final LLO.
The direct re-entry to Earth versus the ISS re-entry benefits of a reduced Delta V values but on the other hands, to implement such a function, the overall lunar stack masses increments (with effects on the needed propellant): hence the energetic cost of the ISS option is again not penalizing.

In the optic of a LEO elements assembly, the number of the multiple Earth-to-LEO missions, needed to deliver the pressurized, the un-pressurized and the propulsive stages of the exploration vehicle in all the four test scenario, has been estimated on the basis of the available launchers performances (e.g. Ariane 5 ECB) in terms of fairing accommodation and payload mass delivered to LEO. For each Earth-to-LEO mission, it has been envisaged the presence of a Guidance Navigation and Control Module in charge to deliver the exploration element to the on orbit assembly point. Assumptions have been also made on the liquid oxygen and liquid hydrogen tanks and systems to estimate the dry mass and dimensions of the propulsive elements.

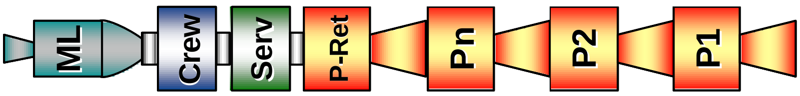
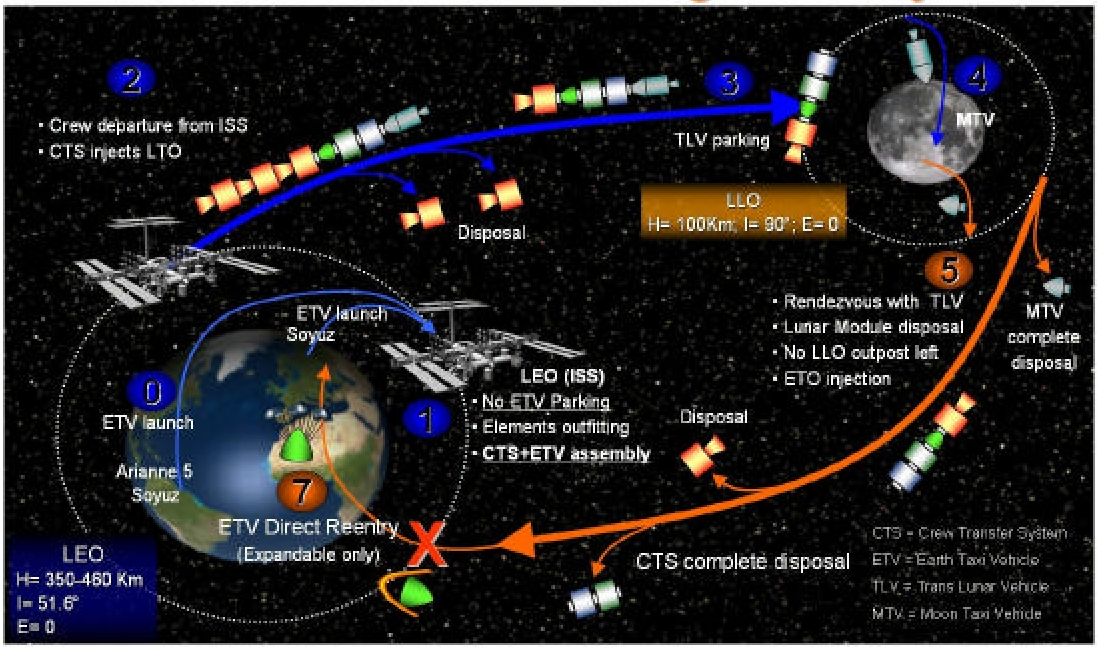


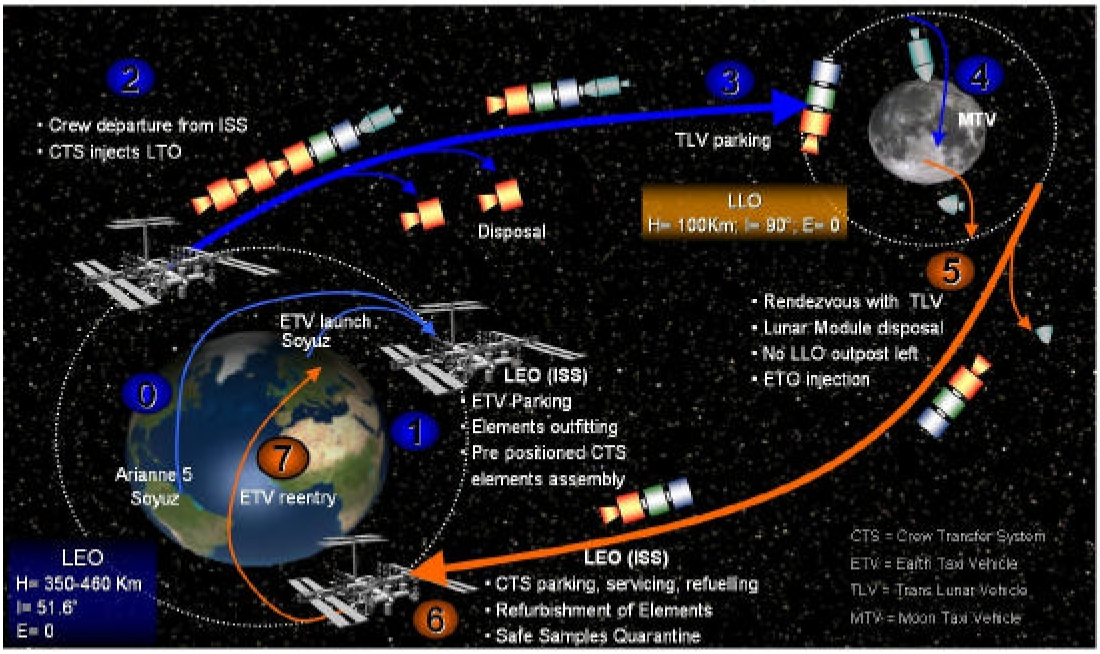
Fig.3-1 Functional architecture of a lunar stack

The results of the parametric analysis, conducted with the current AR5, shows that the propulsive elements will need a partially filled launch with a subsequent propellant on-orbit top off (i.e. on orbit cryogenic propellant management platform) and that only 1 Earth-to-LEO flights separate the scenario 4 ("No ISS utilization") from scenario 2 ("Leaving Port") and another additional flight is present between the scenario 2 and the scenario 1 ("Max ISS utilization").

Scenario 2: ISS as Leaving Port only



Scenario 1: Maximum ISS exploitation



4 The Military Logistics as a potential source of "Spin-in" Methodologies and Approaches

Considering the expected dimensions of the future Space Exploration endeavor and at the same time the necessity to develop a feasible project with a non-infinite funding it is obvious assume a full exploitation of the opportunities offered by the so-called "spin-in" technology transfer. It is worthy to remember, and may be worthy to consider for further investigation, that already in 1984, NASA when listed the different technologies considered as critical for the construction of the International Space Station discovered, with major surprise, that more than half of these technologies were already available in other high-tech sectors.

The commercial civil logistics is no more the simple business of moving things around, but it is day by day more complex offering finely tuned services and based on utilization of new ICT technologies. Despite the successful stories of up-to-date methodologies implementation by the leading logistics companies it is almost impossible to highlight any potential for a "spin-in" because the difference between the "space" and "non-space" sector is not merely about the environment but about the final objective. The smart commercial logistics objective is keeping running round the clock production systems with frequent, on time delivery of goods, management of robotized warehouses and in-time delivery of the final products to the customer.
The confronted challenges are therefore completely different and the adopted solutions are deemed to be not applicable to a space project.

On the contrary, some of the objectives and operative environment of the military logistics are quite similar to the space ones: deploying a crew and a complete system ("Force Element"), sustaining them for a limited period of time in a "harsh" environment on the basis of a transportation planning subject to unpredictable events. Not least important, always more often the logistics must (or should) rely on international partner agreements (coalition forces team) with limited set of standard practice set-up by dedicated agencies (e.g. NATO).

From the above considerations the military sector seems a potential area of investigation for "spin-in" and experiences for what concern the elaboration of partnership strategies, programmatic analyses, operational aspects, design approaches, and high-technology tools and methodologies.

Leaving out the first two points and limiting the attention to the most "technical" issues it is worth to consider that the development of many logistics support phases shall imply the use of new hardware technologies (part of which is already available on the market), to automate as far as possible the defined processes. A first appealing example can be the adoption of RFID TAGs, enabling the unique and automated identification of the system components. That can result in automatic generation of the spare part list, automatic location and retrieving of applicable maintenance procedures, storing and retrieving of information concerning the life cycle data for each single component, etc.

Other example of proper adoption of design approaches is that provided by projects like Eurofighter, Eurojet and NH90, having successfully joined the implementation of the logistic management (since the pre-contractual phase of the project) with the use of new-generation technologies (both software and hardware), thus fulfilling the new and more strict requirements of the weapon system concerning availability and multiple operating environment, with high complexity. These projects has shown the winning nature of the adopted organization model, founded on the dragging power of the large leading industries, cooperating with smaller specialized firms, having an acquired cross-sector and multi-sector experience.

5 The Necessity for International Integrated Teams

In the framework of a future international cooperation for the implementation of the manned space exploration, whatever choice could be implemented:

- Participants bringing their own independently operated, but goal-associated, missions as contributions to a subset of mission goals (ISS-like).
- Participants providing components to an integrated mission on a "best value" basis and selected by a lead systems integrator, taking into account cost, schedule, and performance risk (JSF-like).

the concept of interoperability at global level is of prime importance and should be vigorously applied in each and every phase of the implementation of the "Moon Base" project, in particular for the Logistics tools and methodologies.

As a matter of fact, what will be necessary is no more than foster the working practice of the "International Integrated Product Teams" as currently on-going for the development of products within commercial or military sectors (e.g. programs of NATO interests).

It is worthy to note here that the most important factor enabling the adoption of such a practice is the ensemble of updated ICT technologies for which it can be assumed a significant progress during the near future when the real effort for the "Moon Base" will start. These technologies enable the implementation of concurrent design approaches also among teams scattered all over the world in industrial and research centers if properly networked.

The fully adoption of an "International Integrated Product Team" approach will permit total interchangeability of parts produced by the various partners/participants to the program with improved management of spares and maintenance (nominal or off-nominal) management.

6 Conclusions

Italian aerospace industries have developed through their participation in to the ISS and, in particular, through their tight relationship with NASA and the Major Aerospace U.S. Companies, a significant "competitive position" for what concerns the "Integrated Logistic Support" and "Operations Engineering Support" within manned space infrastructures.
The achieved background is made not only of specific technical knowledge, but also of consolidated working standards and methodologies.
Even if tougher and tougher competition is to be expected in the next forthcoming years, there are good conditions for a positive evolution inside the Exploration Initiative, through proper R&D, technological "spin-in", and continuing improvement based on the ISS "lessons learned".

7 Acknowledgment

The authors intend to declare they are particularly indebted for the elaboration of this brief paper to be intended no more that a stimulus for joint discussions with:

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