POLITECNICO DI TORINO

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

Degree in Aerospace Engineering

Master's Degree Thesis

Development of a modular system for payloads accommodation on spatial platforms

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Abstract

In the background of this new and commercial economy, various projects and mission are turned towards the transportation to Low-Earth Orbit and the management of experiments developed by private entities. To accomplish this demand, also the European Space Agency is working on vehicles and platforms that allow the experimentation in a microgravity environment, as well as the in-orbit validation and demonstration of technologies and the satellites inspection. Such systems could have the advantage of being uncrewed and reusable, therefore the chance of returning experiments to Earth is a very important utility.

The main objective of this study is to provide guidelines and first results of a design and development process of a payload accommodation facility to be installed on space systems aimed to the in-orbit experimentation. The platform should integrate payloads and provide them with structural support, power distribution, data handling and thermal control.

To satisfying the requests of the company that supports this project work, ALTEC SpA, requirements of modularity, scalability and reusability have been considered as the main drivers in the design of the system. Starting from the study of existing facilities, some system engineering activities have been carried out, i.e. stakeholder analysis, functional analysis and definition of requirements. Therefore, after the identification of possible solutions responding to objectives and requirements, a trade-off analysis has been performed, allowing the selection of the optimal solution according to different criteria, defined on the base of mission objectives and stakeholder needs.

The selected solution has been designed through a CAD and the preliminary evaluation of budgets. Necessary equipment for subsystems has been identified among COTS components and a conceptual configuration has been proposed.

Finally, the feasibility of the project has been analysed under two aspects: the technological challenges in the development of the system and its adaption to different payloads and different missions from one side, the compatibility of the facility to the system or the vehicle and its operations from the other one.

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Acronyms

AHP Analytical Hierarchy Process

AIT Assembly, Integration and Test

COTS commercial off-the-shelf

EPS Electrical Power Subsystem

FOV field of view

GSE Ground Support Equipment

HRDL high-rate data link

ILS Integrated Logistic Support

JEM Japanese Experiment Module

LCL latching current limiter

LRDL low-rate data link

MCDM Multi-Criteria Decision Making

MLI multi-layer insulation

MPCB Multi-Purpose Cargo Bay

OBC On Board Computer

P/L payload

RLCL retriggerable latching current limiter

SR Space Rider

TRL Technology Readiness Level

Chapter 1

Payload Accommodation Facilities: State of Art

In this first section, payload accommodation facilities at the state of art are exposed and compared: all these systems are being employed or were employed on the ISS. They differ from each other for structure configuration, installed equipment and subsystems, but their main aim is common: to provide surviving functionalities to the payloads and to allocate them so they can meet their objectives and complete the mission. Such facilities are presented below, distinguishing those that operate in the external environment from those thought for the inside of the ISS.

1.1 ISS External Facilities

Since space is evolving into a new and commercial economy, more and more entities, both public and private, are interested in putting experiments and technologies in orbit, with the objective of testing them in a microgravity environment and when possible, to recover their payloads and analyse results. The International Space Station is, at the moment, the only opportunity to do so. Payloads accommodation systems can be mounted in different sites of the Station, according to the payloads requirements, allowing different views and exposures.

1.1.1 EXPRESS Logistics Carriers

The EXpedite the PRocessing of Experiments to Space Station (EXPRESS) Logistics Carrier (ELC) is a unpressurized platform designed to support external payloads mounted to the ISS starboard and port trusses (P3/P4 and S3/S4 sites) with either deep space or Earth views, as shown in Figure 1.1. External payloads may be accommodated on the ELCs at several locations. Mounting spaces are

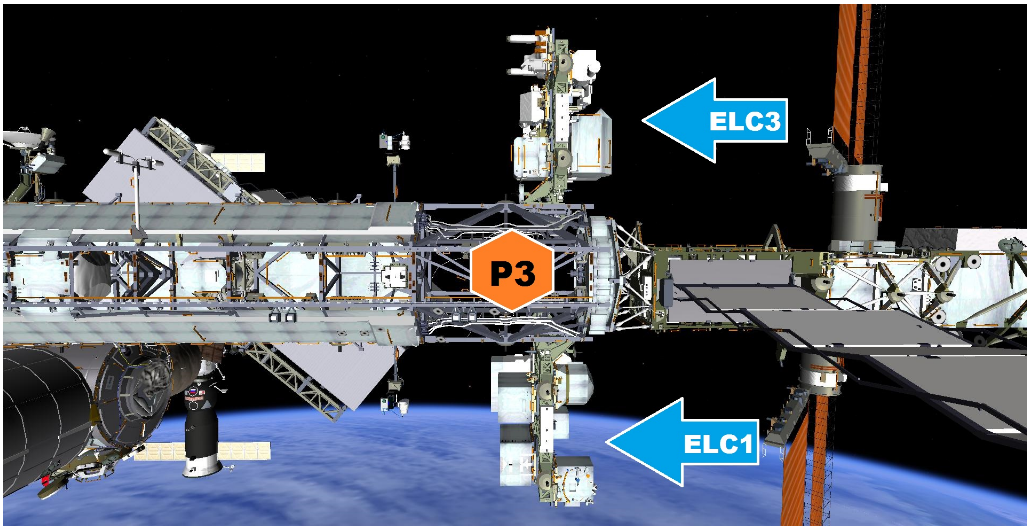

Figure 1.1: EXPRESS Logistics Carrier

provided, and interfaces for power and data are standardized to provide quick and straightforward payload integration.

The ELC is designed to carry a variety of orbital replacement units (ORUs or spares), first-time outfitting cargo, and external payloads (science experiments), which can be mounted on the platform through the Mobile Servicing System, a robotics suite for the assembly, maintenance and resupply of the space station [1]. The ELC, which is fully integrated with mounted cargo/payloads, has been delivered to the ISS in the Space Shuttle cargo bay.

One of primary functions of the platform, in addition to the structural support, is to provide power to the attached P/Ls. Therefore, it is able of linking P/Ls to the two feed lines provided by the ISS: one as primary source for operational use and the other as auxiliary power (keep-alive).

The other primary task of the ELC is to manage data to and from P/Ls and so to link them to the ground. For this reason, sites where ELC is mounted have access to both ISS low-rate data link (LRDL) and high-rate data link (HRDL): attached P/Ls may use the first for data and command distribution, and the second one for payload-to-payload communication and data downlink service.

1.1.2 Bartolomeo

Bartolomeo is newest the P/L hosting platform on ISS, developed and operated by Airbus. It is attached to European Columbus Module and can accomodate P/Ls with sizes from 3U on, providing slots of various dimensions and configuration. A slot can also be shared by smaller payloads by attaching them to the ArgUS

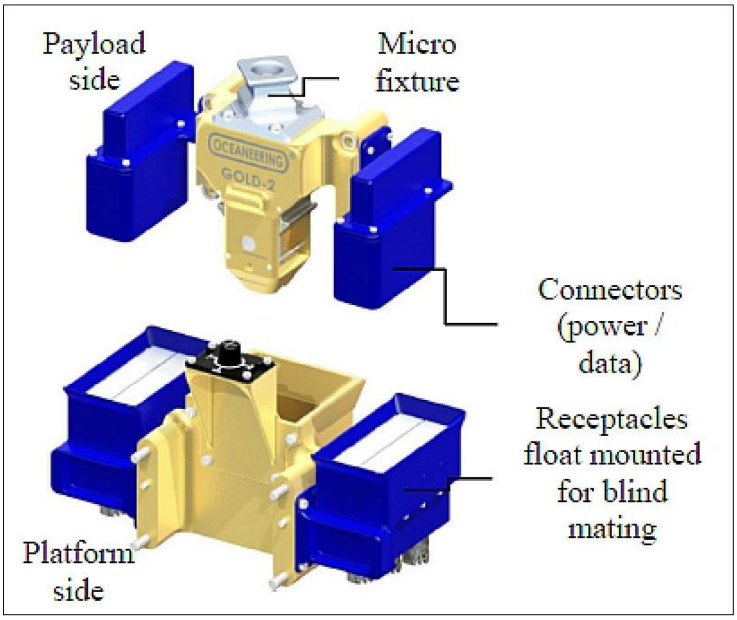

Figure 1.2: GOLD-2 interface

Multy-Payload Adapter.

Bartolomeo brings features to its users which are unique for external platforms [2]:

- Unobstructed view of Earth and space;
- Unpressurized and pressurized launch of payloads;
- Payload or sample return option;
- Active cooling capability;
- Easy access through standardized payload interfaces;
- Enhanced data downlink budget for its payloads.

All payload interfaces use the GOLD-2 (General-Purpose Oceaneering Latching Device-2) interface (Figure 1.2), which allows to remove payloads from the platform using the ISS Robotic Manipulator System and to put them into one of the ISS payload airlocks with appropriate counter interfaces, permitting the return.

As the other similar facilities, Bartolomeo is provided with an avionic system for the power and data management, which leans on Columbus Module interfaces, but it results in being much more competitive: in fact, it provides very good view conditions, and considerable power and data resources, as well as active cooling.

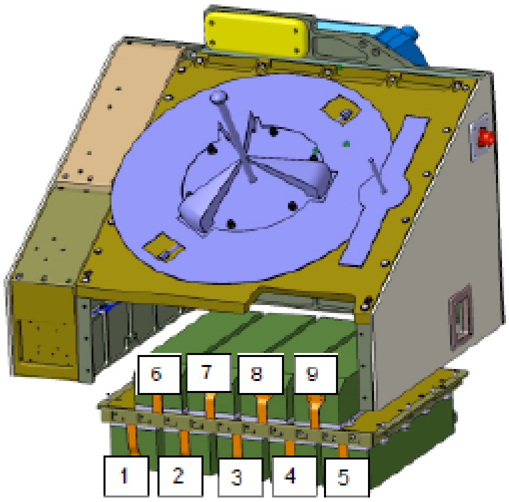

Figure 1.3: NREP Payload Numbering System

1.1.3 Nanoracks External Platform (NREP)

The Nanoracks facility NREP operates experiment payloads in the open space environment while attached to the JEM-EF (JEM External Facility).

The NREP-Payload Baseplate is the interface between payloads and the platform and contains mechanical, electrical, thermal and data interfaces; it has a total capacity of 35 kg. Experiment payloads are nominally packaged in a 4U Cubesat Form Factor and are equipped with a standardized USB 2.0 interface.

NREP payloads can be attached in various configurations to the NREP Baseplate. The baseplate can accommodate up to 5 powered 4U payloads and up to 4 unpowered 3U payloads or unique geometry agreed to per interface control agreement [3]. A nominal configuration with 9 attached payloads is shown in Figure 1.3.

All payloads utilize hex socket type fasteners, in a well defined number: two fastener locations per 100 mm payload length. They also have a soft dock feature and bonding tabs. Electrical connectors, located at the rear side of the base-plate, provide a switchable 28 VDC power outlet, while with the USB 2.0 data bus a 5 VDC power supply is ensured.

1.1.4 Nanoracks Bishop Airlock

The Bishop Airlock is a commercially-funded airlock module whose primary objective is to increase the payload volume able to move in and out of the Space Station.

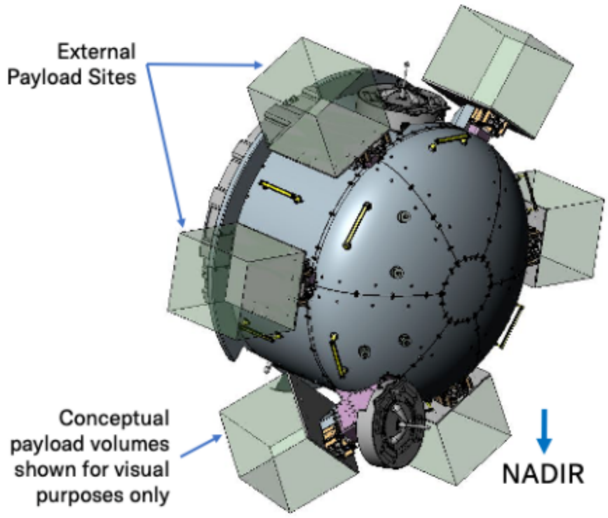

Figure 1.4: Bishop Airlock

Furthermore, it expands the Nanoracks payload hosting capabilities by providing six external sites with different pointing options towards Earth (Figure 1.4). It was berthed to the Tranquillity Module on 19 December 2020 by the Canadarm2.

The facility supports P/Ls with a maximum electrical power of 700 W per payload that must be coordinated by Nanoracks, and with 100 Mb/sec of data rate. It also has a data storage capability within the avionics. Redundant fiber optics and coaxial connections are also available and terminated inside of Airlock pressure shell [4].

1.1.5 Japanese Experiment Module-Exposed Facility (JEM-EF)

The JEM-EF is an external platform for conducting scientific observations, Earth observations, and experiments in an environment exposed to space. The JEM-EF/payload interface on the JEM-EF side is the exposed facility unit (EFU). There are a total of 12 EFUs on the JEM-EF, nine of which are available for users. The other three EFUs are used for the JEM-experiment logistics module (ELM)-exposed section (ES) and for temporary storage [1].

JEM-EF provides to payloads electrical power, data and active thermal control. The electrical power is distributed through two separated buses: 3 kW of main power and 100 W of survival power. For the communication, JEM-EF has several channels divided in Ethernet, video data and high-data-rate.

The Japanese platform is the only one within the U.S. on-orbit segment to have

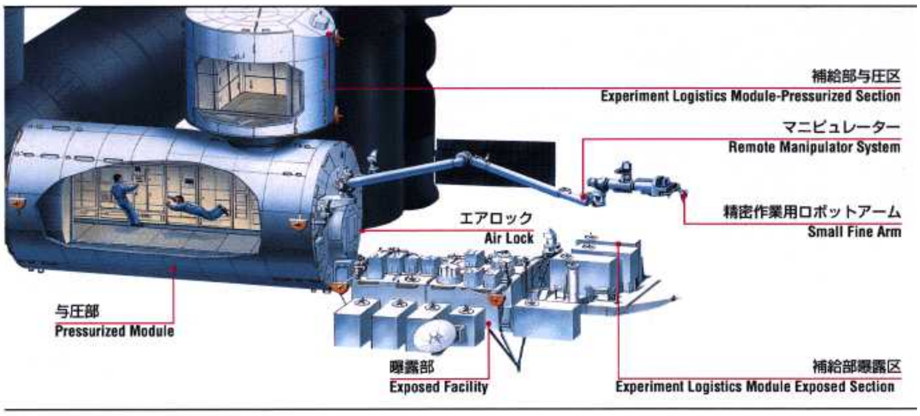

Figure 1.5: JEM-EF components

a P/L airlock, allowing the passage of payloads between the pressurized cabin and the space. JEM-EF is also equipped with a robotic arm (Figure 1.5) that moves the payload between the airlock and its placement on the platform, and with a slide table that moves experiments or ORUs between the pressurized module (PM) and the EF.

1.2 ISS Internal Facilities

In the following section, some of the internal facilities installed on the ISS are exposed. They provide to P/Ls microgravity environment as well as ISS resources and crew members. The purposes and the capabilities of these systems are very varied, as explained in the document *International Space Station Facilities, Research in Space 2017 and Beyond* [6], here only those one that have similar characteristics and purposes to the facility under study (i.e. accommodation of payloads and power and data handling) are considered.

1.2.1 EXPRESS Racks

EXPRESS Racks are one of the primary means of accommodating scientific hardware in the habitable volume of the ISS. EXPRESS Racks are the most flexible modular research facility available on the ISS, and are used by NASA, JAXA and ESA.

They enable simple integration of multiple payloads with standard interfaces that can accommodate up to ten small payloads, resulting in a total operation capability of eighty experiments. Each payload can operate independently of one another. The EXPRESS Rack facilities are comprised of several subsystems that

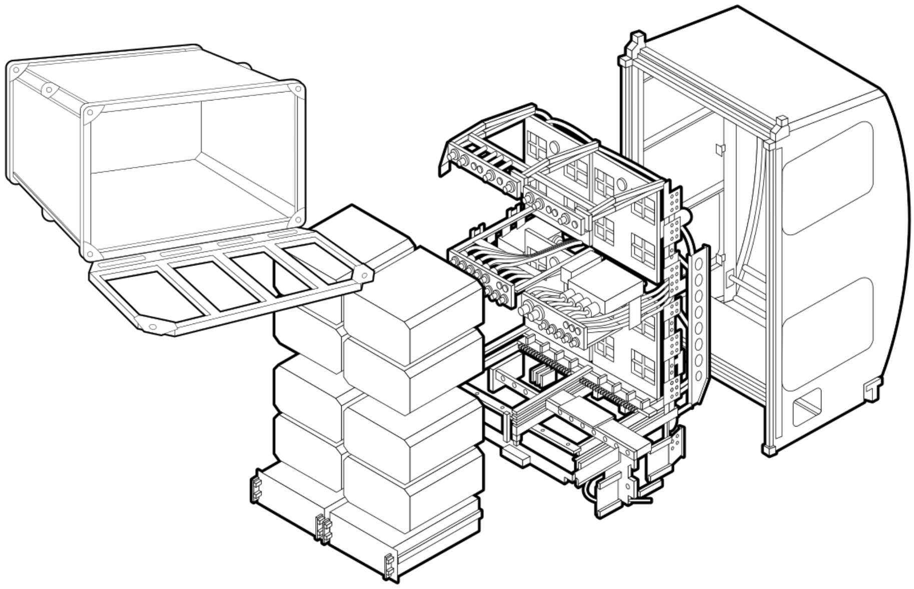

Figure 1.6: ISPR Composition

enable operations and support the experiments with stowage, power, data, command and control, video, water and air cooling, vacuum exhaust and nitrogen supplies.

Each research facility is housed in an International Standard Payload Rack (ISPR) (Figure 1.6), a container that serves as the facility's exterior shell. Facility experiments can be directly controlled by the ISS crew or remotely controlled by the Payload Rack Officer (PRO) at the Payloads Operations Integration Center (POIC) at Marshall Space Flight Center [5].

1.2.2 Nanoracks Platforms

BlackBox and Nanode are two of the commercial internal facilities developed by Nanoracks that interface EXPRESS Racks lockers with customer payloads up to 18U in the first case and with Nanolab Modules in the second. They both provide mechanical mounting points and electrical connections for power, data, and communication capabilities. They both have same dimensions of lockers but while the BlackBox is a closed structure (i.e. a box) as shown in Figure 1.7, the mainframe of Nanode consists of a baseplate and two lateral surface for connections (Figure 1.8).

Black Box exists with two mounting configurations: bare interior panels or a bolt hole grid. In the first case users are able to affix payloads to the interior surfaces using either hook and loop fasteners or doublesided tape, while the second uses a grid of 2-inch centers of fasteners on the base plate, that protrudes into the interior volume of the Black Box [7].

Four fans (two in and two out) allows the airflow in both BlackBox avionics and in the payload volume. Data and power connections are provided through Type A, USB 3.0 connections.

Nanode interfaces with P/Ls through its base where there are 12 positions, 4 per each of the Nanode's 3 retention slots. Each position also includes a key feature (head of a cap-screw) to ensure correct orientation of the connecting payload [8]. Its capability is approximately 4U*3.5U*2U and it can accommodate up to 12 Nanolab Modules.

Figure 1.7: BlackBox

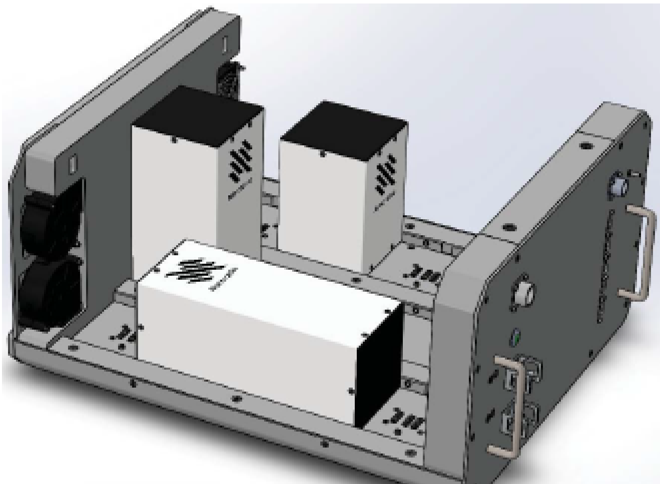

Figure 1.8: Example of Nanode Payloads Accommodation

Chapter 2

Preliminary Study

First steps in the preliminary design of the facility for P/Ls accommodation are here presented.

The study bases its modus operandi on ECSS Standards, in particular on those regarding Space Engineering (i.e. ECSS-E-ST-10C Rev.1, ECSS-E-ST-10-06C, ECSS-E-10A).

Starting from the description of the case study, considered for the design of the platform, a system engineering approach is adopted: firstly, possible stakeholders are identified together with their needs, which are prioritized and then transformed into mission objectives; therefore, high level requirements are derived and formalized. A functional analysis is set as a logical decomposition process of the system to design, aimed at defining alternative mission architecture models and end product functional requirements. Iterations of the functional analysis allow to derive functional requirements for the system and lower level ones for subsystems, equipment and components.

This study, being part of an early phase of the project, specifies requirements up to the equipment level, giving guidelines for the selection of it among commercial off-the-shelf (COTS) components market. Despite the employment of COTS components is the preferential way for the facility design, some other solutions can be also evaluated during the project evolution, if needed.

The system engineering process results in the identification of four architecture concepts of the platform, which are then compared and submitted to a trade-off analysis.

2.1 Case Study

In order to refer the design to something actual, the Space Rider (SR) vehicle is considered as use case.

The SR is an affordable, independent, reusable end-to-end integrated space transportation system for routine access to and return from low earth orbit. Integrated with the Vega-C Launcher System, Space Rider will transport payloads for an array of applications, orbit altitudes and inclinations compatible with the performance of the launch system [13]. The variety of applications includes:

- micro-gravity experimentation;
- in-orbit demonstration and validation of technologies;
- in-orbit application for Earth monitoring;
- educational missions.

The vehicle will offer to P/Ls:

- exposure to low gravity up to two months;
- possibility of a field of view to Earth or to Deep Space;
- reduced safety constraints with respect to manned operations;
- in-flight (i.e. power, telemetry, tele-command, thermal control, attitude control) and ground services;
- late installation and early post-flight retrieval.

SR is composed by two modules: the AVUM Orbital Module, and the Re-entry Module, the reusable part of the vehicle that integrate the Multi-Purpose Cargo Bay (MPCB) for P/Ls accommodation. The Cargo Bay also provides for the necessary structures for the mechanical fixation and the thermal control, as well as interfaces for power and data. There are eight compartments for the payloads facility accommodation, with different dimensions and capabilities, as shown in Figure 2.1. Even though the system shall be designed with a modular approach in order to be reused for the installation of different payloads and accommodated in different compartments, in this conceptual design, it is thought to be installed in a particular location: the *TOP Central Forward* one, that has the capability to be opened to space environment.

2.2 Stakeholder Analysis

"The first step in analyzing and designing a space mission is to define mission objectives: the broad goals which the system must achieve to be productive" [14]. In order to complete this first task of the system design, it is necessary to identify

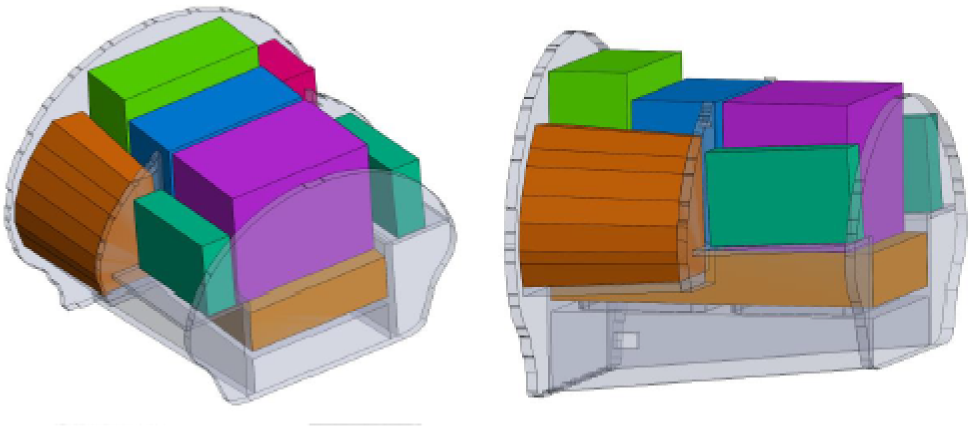

Figure 2.1: Cargo Bay configuration showing available locations

which are the possible stakeholders, namely any entity, organization or person that impact and can condition the design of the space system, in this case, of the payload accommodation facility. Stakeholders can be users or operators, but also sponsors and developers. They can be grouped and classified in the following categories:

- companies/entities that develop the platform;
- companies/entities that produce payloads;
- companies/entities that manage the payload-platform integration;
- companies/entities that manage the platform-vehicle integration;
- space agencies that operate the mission.

They are clearly all interested in the successful evolving of the project, supporting different needs and values with different influence and interest, that are depicted in Figure 2.2. A couple of scores from 1 to 9 has been given to each of stakeholders, one for the influence and the other for the interest, which are respectively a measure of the power of supplying time and resources and of the involvement in the success of the mission. According to this mapping, the needs should be certainly prioritized and eventual conflicts should be solved, but in this early phase of the project they are all identified as equally influential on the design of the system and considered with the same priority. The stakeholder needs are therefore translated into the following mission statement:

"To develop a multipurpose facility for payloads accommodation on space systems, exploring modular and scalable solutions to reuse the platform for successive missions and for different payloads. To promote fast modification, integration and verification processes."

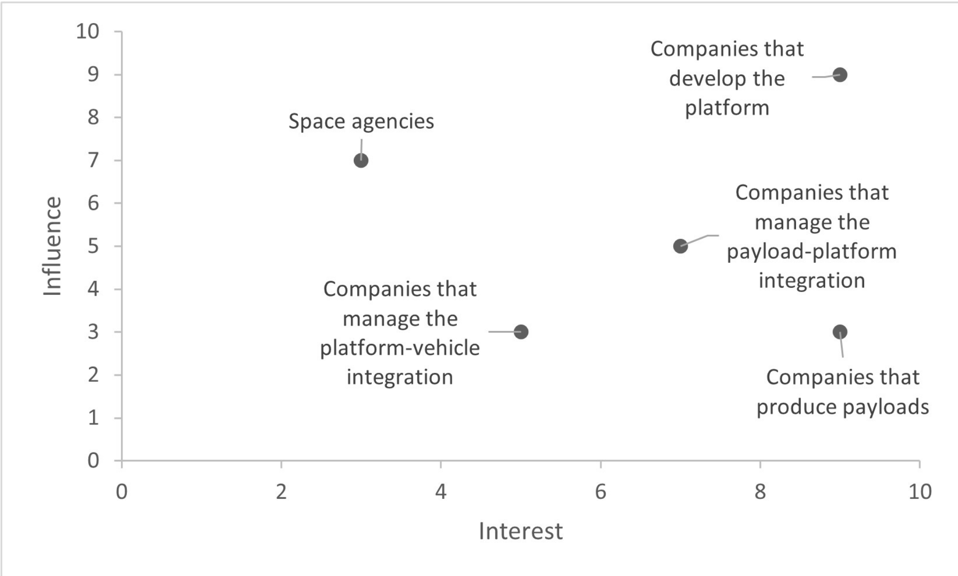

Figure 2.2: Stakeholders mapping

which resumes the following objectives and constraints prescribed by the company:

- To accommodate payloads in the context of an orbital mission of a re-usable vehicle;
- To adapt the system to different kind of payload;
- To adapt the system to different space vehicles;
- To provide power, data handling and thermal control (optional) to the payloads;
- To re-use the system for following missions;
- To guarantee an operative lifetime of six years, reducing maintenance interventions as much as possible;
- To guarantee ease of scalability in terms of whether dimensions and installed subsystems.

After the identification and the formalization of qualitative objectives, mission requirements, that are quantitative expressions of how well objectives are achieved, can be defined and classified.

2.3 Definition of Requirements

According to the ESA standards, and particularly with reference to the ECSS-E-ST-10-06C, different categories of requirements can be identified: mission constraints, functional, interface, environmental, operational, physical, configuration, design, verification.

From the high-level requirements that mainly regard the system level it has been possible to get more and more specific and derive requirements related to subsystems and components. Beside the hardware component, requirements regarding operations, integration, test and verification have been defined, too. For each requirement a method of verification has been identified as well as the traceability, that is the owner or the *father* requirement. According to ECSS-E-HB-10-02A standard, verification methods are the following:

- **test** (T): verification by test shall consist of measuring product performance and functions under representative simulated environments;
- **analysis** (A): verification by analysis shall consist of performing theoretical or empirical evaluation using techniques agreed with the Customer;
- **review of design** (RoD): verification by review-of design shall consist of using approved records or evidence (e.g. design documents and reports, technical descriptions, engineering drawings) that unambiguously show that the requirement is met;
- **inspection** (I): verification by inspection shall consist of visual determination of physical characteristics.

In the following tables, identified requirements are reported, the first column (the *ID*) contains a code whose first three letters indicate the category.

The first category of requirements, which derive straight from the mission objectives, are the mission constraints (Table 2.1). They generally address orbit requirement, duration, assembly, utilization timing and needs, scientific objectives and define the mission success criteria. In this particular case, being orbital characteristics and mission duration dictated by the vehicle operations and schedule, mission constraints mainly derive from the SR user manual and ensure the compatibility of the facility with the vehicle.

MISSION REQUIREMENTS			
ID	**Text**	**Father/ Traceability**	**Verification Method**
MIS001	The system shall accommodate P/Ls for LEO experimentation missions	Agreement	RoD
MIS002	The system shall be adaptable to different vehicles/space systems	Agreement	RoD
MIS003	The operative lifetime of the system shall be of at least 6 years	Agreement	RoD
MIS004	The facility handover shall follow operations timeline of the vehicle	SR User Guide	RoD
MIS005	The system shall be employed for different kinds of P/L	Agreement	RoD
MIS006	The system shall be employed for commercial purposes	Agreement	RoD

Table 2.1: Mission constraints and requirements

The functional requirements need to be specified for all intended uses of the product over its entire lifetime. Functional analysis, which is described in Section 2.4, is used to draw out both functional and performance requirements. Functional requirements define what functions need to be done to accomplish the objectives, while performance requirements define how well the system needs to perform the functions [15]. In Table 2.2, functional and performance requirements are presented.

FUNCTIONAL REQUIREMENTS			
ID	**Text**	**Father/ Traceability**	**Verification Method**
FUN001	The system shall ensure structural support, thermal control, power distribution and data handling to the P/Ls	Agreement	RoD
FUN002	The system shall regulate electrical power supplied by the vehicle	FUN001	RoD

FUN003	The system shall distribute electrical power among the P/Ls	FUN001	RoD
FUN004	The system shall protect the P/Ls from the vehicle EPS failures	FUN001	RoD
FUN005	The system shall receive commands from the vehicle (which receives them from the GSs)	FUN001	RoD
FUN006	The system shall send commands to the P/Ls	FUN001	RoD
FUN007	The system shall receive telemetry and data from the P/Ls	FUN001	RoD
FUN008	The system shall send telemetry and data to the vehicle (which sends them to the GSs)	FUN001	RoD
FUN009	The system shall process P/Ls data	FUN001	RoD
FUN010	The system shall provide the needed quantity of main power according to P/Ls demand	FUN003	A,T
FUN011	The system shall provide a survival power line	FUN003	RoD
FUN012	The system shall thermally insulate surfaces and components	FUN001	RoD
FUN013	The system shall thermally decouple selected interfaces	FUN001	RoD

Table 2.2: Functional Requirements

The interface requirements (Table 2.3) define how the facility interact with the system in which is integrated and with the payloads it accommodates. There are different types of interfaces, they include: mechanical, electrical, thermal and data. Also interfaces associated with all product life-cycle phases (e.g. test equipment, transportation system, Integrated Logistic Support (ILS) systems) should be considered [15]: however, requirements regarding these aspects can't be specified so far because of the lacking of data inherent to this phase of the project. Since final information about interfaces of SR MPCB are not known at the moment of the study, standard connections are considered for power and data, as well as for mechanical ones. Regarding the coupling with payloads, the choice of interfaces is still open and will be defined during following detailed studies.

INTERFACE REQUIREMENTS			
ID	**Text**	**Father/ Traceability**	**Verification Method**
INT001	The system shall have mechanical interface with the P/Ls	MIS001	RoD
INT002	The system shall have mechanical interface with the vehicle	MIS002	RoD
INT003	The system shall have functional interface with the vehicle	MIS002	RoD
INT004	The system shall have functional interface with the P/Ls	MIS001	RoD
INT005	The system shall have one input main power interface with the vehicle	INT003	RoD
INT006	The system shall have one input survival power interface with the vehicle (if the vehicle provides for it)	INT003	RoD
INT007	The system shall have one output main power interface per P/L	INT004	RoD
INT008	The system shall have one output survival power interface per P/L	INT004	RoD
INT009	The system shall have standard databus connections (e.g. Ethernet, SpaceWire) with the vehicle	SR User Guide	RoD
INT010	The system shall have one data interface per P/L	INT004	RoD
INT011	The system shall have couplings for installed thermal devices (e.g. MLI, thermal washers, thermal fillers)	FUN001	RoD

INT012	The system shall have mechanical interface with the transportation system	MIS002	RoD

Table 2.3: Interface Requirements

Requirements derived from the environment the system will encounter during all its life-cycle phases, including ground test and storage, transportation, launch and normal operative conditions, should be included. They concern acceleration, shock, thermal, EMC and space-external environments (the last one regarding atomic oxygen, external vacuum, cosmic radiation and solar light) [13]. Environmental requirements are listed in Table 2.4.

ENVIRONMENTAL REQUIREMENTS			
ID	**Text**	**Father/ Traceability**	**Verification Method**
ENV001	The system shall withstand the space environment	Agreement	T
ENV002	During launch phase, the system shall support the mechanical and thermal loads inside SR MPCB in the selected virtual locker and compatible with VEGA C Launch Vehicle	Agreement	T
ENV003	The system shall be compatible with electromagnetic environment defined by the emission radiated by SR towards the MPCB	ENV001	T
ENV004	The system shall deal with a vacuum pressure that can be as low as $0,133 * 10^{-6} kPa$	SR User Guide	T
ENV005	The system shall deal with an atomic oxygen flux of $10^{20} oxygenatoms/cm^2/day$ in the ram SR direction	SR User Guide	T

Table 2.4: Environmental Requirements

Other categories of requirements (i.e. operational, logistic support, physical, configuration, design and verification) are collected in Table 2.5. Operational requirements are related to system operability and so to operative modes, in orbit operations in general and communication with the ground systems. Logistic support ones include constraints concerning the maintenance, the transportation, the handling and the storage but also the training of users and related documentation. Physical requirements are those that ensure physical compatibility and that are not contained in interface and design ones. Configuration requirements regard the composition of the system and its organization, while design ones concern design and construction standards, but also selected components and materials. Finally, verification requirements are related to the imposed verification methods, such as compliance to verification standards, usage of test methods or facilities.

OTHER REQUIREMENTS			
ID	**Text**	**Father/ Traceability**	**Verification Method**
OP001	The system shall be operative during the whole experiment window	MIS001	A
LS001	Maintenance intervention shall be reduced to inspections and non-invasive activities	Agreement	RoD
PHY001	The buses for the main power and the survival power shall be separated	FUN001	RoD
PHY002	The system dimension shall be optimized to accommodate selected P/Ls	CON001	RoD
CON001	The system shall be composed by modular components	Agreement	RoD
CON002	The system shall be scalable in terms of installed subsystems	Agreement	RoD
DES001	COTS components shall be employed as much as possible	Agreement	RoD
VER001	The system shall comply safety requirements dictated by the vehicles	MIS002	T

Table 2.5: Other requirements

All the requirements had an impact on the design of the platform since its first draft concept: they entailed a series of properties that the system should have that will be evaluated during the trade-off analysis. The last ones are:

- ease of scalability;
- modularity;
- fast and simple Assembly, Integration and Test (AIT) process;
- adaptability to different types of payload and mission;
- standardization of interfaces.

2.4 Functional Analysis

In order to derive functional requirements of the facility, a functional analysis is performed through a functional tree (shown in Figure 2.3). It represents in a hierarchical way the functionalities that the system, the subsystem and then the components shall perform with their logical connections. Starting from high level requirements and going down in the tree, functions are decomposed into more and more specific one and they answer to the question *"how?"*, while going up again it is clarified *"why?"* that particular function is needed. In this way, lower level functions can be both part of the higher functions or additional ones.

As it can be seen in the Tree, high level functions, arranged according to a logical process, cover the mission objectives: the platform should clearly withstand the space environment and it is designed to act as a bridge between the vehicle (i.e. Space Rider) and the P/Ls, providing for accommodation and necessary interfaces to them and finally it is thought to operate in a commercial missions context, so it shall accomplish standards given by the space agency that operates the mission, after being integrated and verified by the developing company.

Two of the high level functions are "to accommodate P/Ls of various type and dimensions" and "to provide power, thermal control and data handling to the P/Ls": in addition to provide proper support and couplings to the P/Ls, and to ensure them power, data handling and thermal control, the facility shall be capable of giving all the additional functionalities needed by the selected P/Ls. They can be, for example, the capability of a field of view (FOV), so the facility shouldn't physically obstruct the view on external space, or the ability in providing a thermal control in the whole internal volume of the system; in this case, this functionality can be enabled only by a closed and thermally insulated structure. Since, enabled additional functionalities depend on the particular configuration chosen for the facility, they are not inserted in the functional tree, but their feasibility is discussed in the trade-off analysis reported in Chapter 3.

Beside the functional tree, a Product Tree is defined (Figure 2.4), too. According to ECSS-E-10A Standard, it "describes the hierarchical breakdown of a complex system into lower level as necessary to fully define the system". It represents a systematic subdivision of the product into discrete and related elements to be provided in order to accomplish functions declared in functional tree, giving in this way a graphical overview of the entire system.

Four subsystems are identified and broken down into components or units:

- **Structure**: it is the frame and the core of the facility and represents the main discriminating factor among the solutions then compared in the trade-off analysis. It shall give structural support to the P/Ls and provide for all necessary couplings with them and with the Cargo Bay. In order to ease the modularity required to the facility design, solutions made of standardized components, like additive manufactured panels, are investigated.

- **Electrical Power Subsystem**: it is necessary to distribute power supplied by SR to P/Ls and if needed, to regulate it. To limit overcurrent and protect power lines directed to P/Ls from surges, current limiters should be considered. An health monitoring system can be installed too to monitor the state of the Electrical Power Subsystem (EPS) by employing temperature, voltage and current sensors linked to the On Board Computer (OBC).

- **Data Handling Subsystem**: this subsystem is responsible for data and commands management, working as means between the vehicle, linked to ground stations, and the P/Ls. Its installation can be expected according to the needs of installed P/Ls; whether P/Ls data do not need processing before the transmission to SR OBC and then to the ground, this subsystem is limited to wiring and eventually to backup memories (SD cards).

- **Thermal Control Subsystem**: depending on the configuration of the selected alternative, the thermal control can be expected either only at the contact surface between the facility an the P/Ls or in the whole volume enclosed by the structure. To limit the complexity of the subsystem, passive components shall be employed, like a multi-layer insulation (MLI) system or thermal washers or fillers in most sensible interfaces. In the case of P/Ls do not need particular temperature range different by that ensured by the thermal control system of the MPCB, this subsystem shouldn't be provided.

From all the considerations done so far, the necessity of a scalability in terms of installed equipment emerges and shall be considered in the design of the facility.

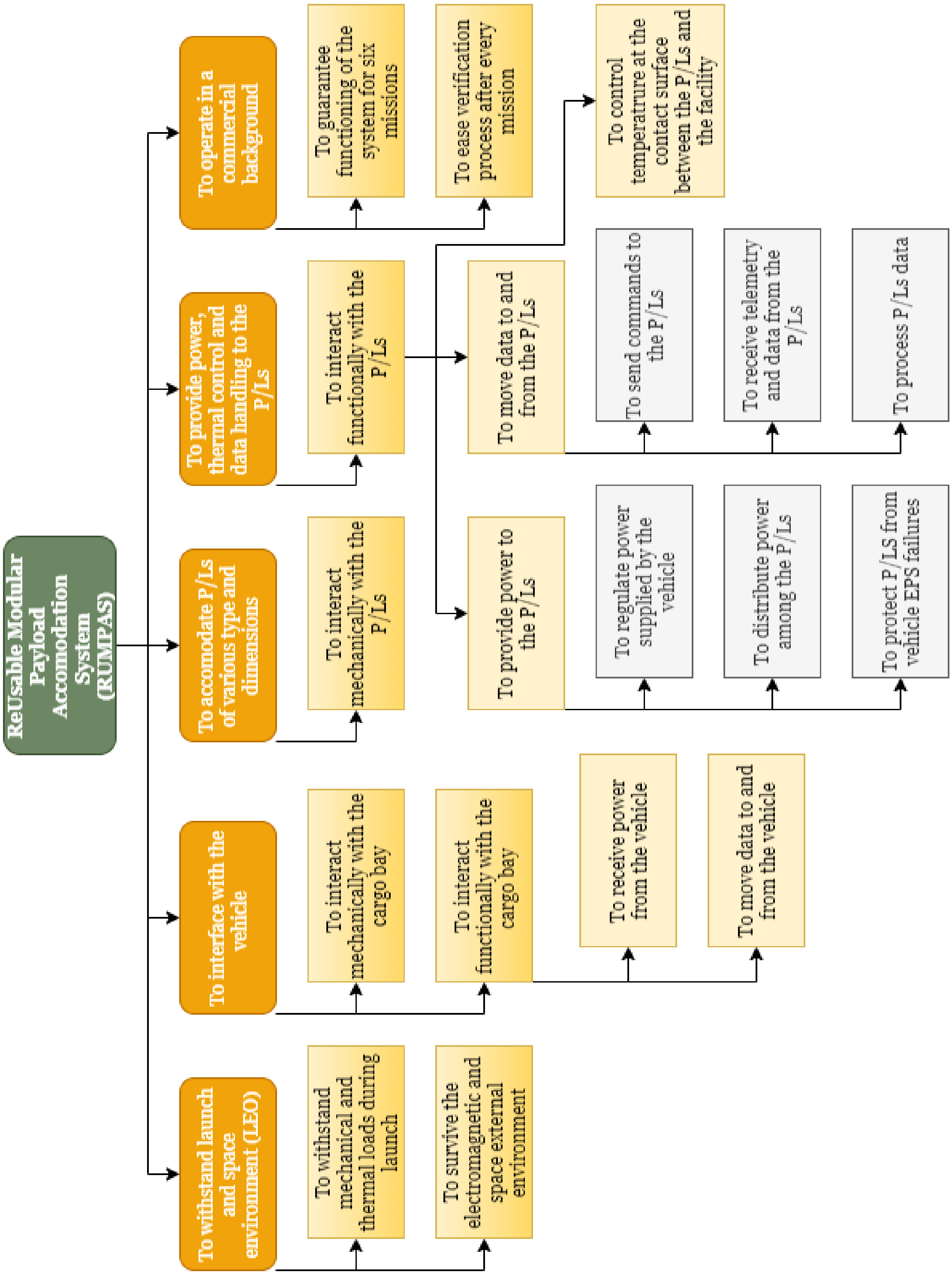

Figure 2.3: Functional Tree

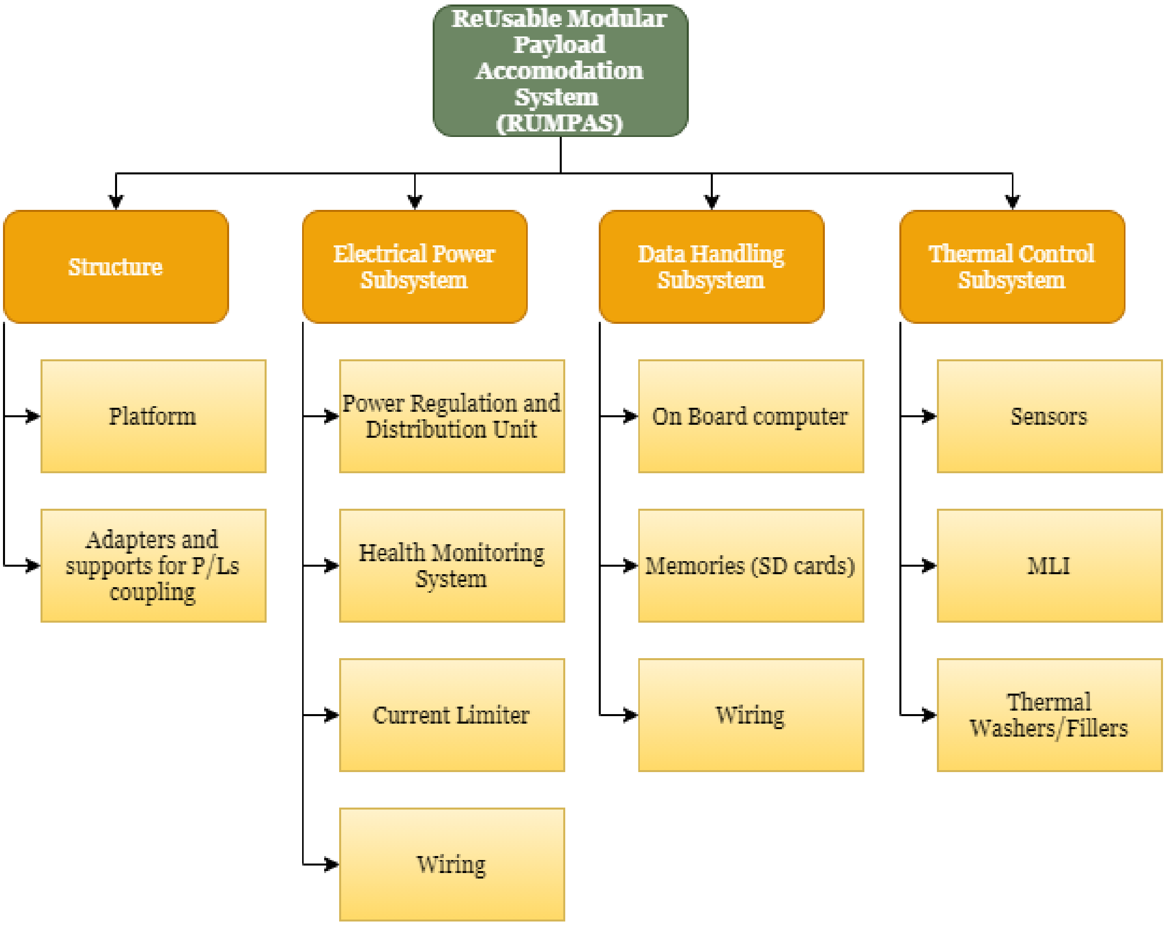

Figure 2.4: Product Tree

Chapter 3

Trade-off Analysis

At this point of the study, in order to support the platform conceptual design, it is necessary to carry out a trade-off analysis that allows the identification of the optimal solution, satisfying stakeholders needs and so complying with requirements. This process also contributes to point out differences among the various concepts of the facility, therefore to highlight which are strengths and lacks of each one. Since the whole study is at a preliminary phase, the results are to be considered open and the analysis should be repeated whenever additional information and constraints of the mission will be known.

In this chapter, various architecture concepts for the facility are presented, then the criteria identified by the stakeholders analysis are explained and prioritized. With these criteria the alternatives are evaluated and compared to each other. Finally, results of the analysis are exposed and their robustness is assessed with the sensitivity analysis.

To carry out this analysis a Multi-Criteria Decision Making (MCDM) technique is used, so that formal and quantitative reasoning is provided. One such MCDM technique is the Analytical Hierarchy Process (AHP): it takes into consideration all quality attributes, priority weights of design alternatives for individual quality attributes and priority weights among the quality attributes themselves [16].

3.1 Definition of alternatives

First step of the trade-off analysis is the definition of the alternatives under evaluation. Four concepts are defined to meet the requirements for the facility under study, i.e. an interface platform to accommodate and manage payloads on the SR vehicle. The concepts are the results of systems engineering processes, e.g. functional analysis, and the enquiry of the current state of the arts, specified in their characteristics and differences as follow.

- **Open**: this solution is formed by a plate, attached to the MPCB by supports (or by a plate, in order to increase robustness, so the resulting structure is a "L"), made of panels of standard dimensions (e.g. 10*20 cm) linked to each other by male-female junctions. Panels can be created by additive manufacturing and for this reason can be adapted to the mechanical interface required by the P/L (due to the limited cost of production and integration, panels can be substituted even after each mission, if needed). A "black box" can be arranged close to the structure, in the required position for the coupling with SR MPCB interfaces (power and data), containing all the components needed for the distribution of power to the P/Ls, the data handling and eventually for the thermal control of the contact surface between the platform and the P/Ls. Cables for power and data emerging from the box are bound to panels by tracks and reach P/Ls' power and data interfaces. If the thermal control is implemented, the panels should be provided with temperature sensor and heaters or other thermal control devices;

- **Closed**: this alternative is composed by a closed structure (attached to the MPCB along one facet) made of an Aluminium frame and panels linked to the frame by threaded joints. Panels have similar characteristics to the open solution ones. The concept of the "black box" can be adopted also for this solution, with the difference that cables can be located inside of the metallic frame. P/Ls can be fixed to the structure along more than one side and occupy the whole internal volume. With this solution and the appropriate equipment (i.e. MLI or electrical heaters), the thermal control can be ensured inside the structure, and not only at the contact surface between the P/Ls and the facility;

- **Half-closed**: this option is thought as a hybrid one between the first two; in fact its structure is similar to the closed one but it has an uncovered side. The concept is once again to use a metallic frame and some panels, and a separated box containing subsystems equipment. P/Ls can be fixed to the structure along more than one side but still have a field of view on the environment outside the facility thanks to the open side. The thermal control of this solution is like the open structure one: it is possible to ensure a certain temperature only at the contact surface;

- **Multi-beam**: this solution provides for a tubular structure (with circular or squared section), fixed to the MPCB at its root. The structure can have a variable length, being made of standard beam elements that can be linked one to the other to result in a long structure than necessary. In this case, P/Ls are fastened to the facility along one facet where power and interfaces are located too. Subsystems equipment can be arranged in the inside of the structure and directly linked to the P/Ls or contained in a separated box as the other solutions. The possible configurations are with a single central beam or with multiple beams, according to the dimensions of the locker and the P/Ls. The thermal control can be ensured only at the interface between the facility and the P/Ls.

	Open	**Closed**	**Half-closed**	**Multi-beam**
Power Management and Distribution	x	x	x	x
Data Handling	x	x	x	x
Capability of FOV	x	-	x	x
Thermal Control at the Surface	x	x	x	x
Volumetric Thermal Control	-	x	-	-

Table 3.1: Functionalities of alternatives

As it is shown in Table 3.1, each solution enables different functionalities. Power management and distribution and data handling are the two mandatory functions that the system should be able to perform, as declared in mission requirements. Therefore all the alternatives have the capability of managing and distribute power among P/Ls arriving from SR EPS, and of handling P/Ls data and telemetry, as well as, sending to them commands from SR OBC. The capability of a FOV is enabled by those solutions that have one or more open sides, while it isn't allowed by the closed one. On the other side, the closed solution gives the possibility of thermally controlling the facility internally, and not only at the contact surface between the system and the P/Ls, as the other three alternatives do.

3.2 Definition of criteria

The other necessary step in setting the trade-off analysis is to declare and define the criteria through which the alternatives will be evaluated and classified. For each criterion, parameters that measure it and their formulation are specified to make possible the unequivocal assignment of scores to the four options. The employed criteria are resumed in Table 3.2. For writing simplicity, the first column of the table contains an *ID* that is used from this moment on to refer to the respective criterion.

ID	Criterion	Parameters	Source	Range
ADAPT	Adaptability to different kind of P/Ls	Number of P/Ls that are enabled by the functionalities of the alternative	Performance	[1-13]
REC	Reconfigurability	Level of complexity of the interventions aimed at adapt the platform to new configuration requirements in terms of effort (evaluation of the modularity)	Operations/ production	[1.26-2]
INTS	Integration Simplicity	Level of complexity of integration process with SR Cargo Bay (number of mechanical and functional I/Fs, handling, standardization of procedure and GSE)	Ground operations (integration)	[1-4,5]
FLIH	Flight heritage of platforms with similar characteristics and configuration	Level of similarity with TRL 9 facilities	Reliability	[2-8]
VOL	Volume allocation capability	Percentage of the Virtual Locker volume usable for the P/Ls allocation and estimated mass of the facility	Performance and cost	[1-4]

Table 3.2: Criteria definition

3.2.1 Adaptability to different kind of P/Ls

This criterion measures how much the facility is versatile in terms of how many different type of P/L can accommodate ensuring all necessary functions. Assuming that the totality of P/Ls interested in general in this kind of mission can be proportionally represented by those that were candidate for the first mission of

Space Rider but have been excluded from the selection, it is possible to quantify this criterion through the number of P/Ls that a certain alternative enables due to its functionalities, exposed in Section 3.1.

Types of P/Ls that can be installed on SR are various (remote sensing, microgravity experiments, telecommunications, in-orbit technology testing and demonstration, etc), as their purposes are. Considering, as mentioned before, candidate P/Ls for the first mission of SR, it is possible to find out which functionalities they need to carry out their mission and so which alternatives allow it. Their purposes are:

- microgravity (it doesn't need particular features and doesn't require thermal insulation);
- radiation environment study (they need a direct interaction with the external environment so they can't be closed into a box);
- pointing (they should point an antenna towards Earth so they must have an unobstructed view);
- Earth observation (they clearly need a FOV).

Therefore, according to Table 3.1, the alternatives "Open", "Half-closed" and "Multi-beam" enable all the seven candidate P/Ls since they have one or more open sides and so the capability of a FOV. The "Closed" solution instead, can accommodate only the microgravity P/L and so only one in the considered seven.

Formulation used to quantify this criterion is a linear function: calling x the number of additional P/Ls that can be installed into the particular solution (in order to develop a usable facility, at least one payload of those candidate should be accommodate, for this reason the *additional* ones are evaluated), the chosen function is $f(x) = 1 + 2x$. The constant term represents the minimum number of P/Ls to be installed, under which it has no sense to consider the alternative at issue, while the gain "2" is added to emphasize differences among alternatives and to give importance to this criterion. The adaptability is, in fact, a mandatory characteristic for the reusability of the system.

3.2.2 Reconfigurability

Since one of the functional requirements of the system is that it shall be scalable and reconfigurable so that it can be repurposed for following missions of the vehicle, it is necessary to evaluate the level of complexity of the interventions aimed at adapt the platform to new configuration requirements. So the chosen parameter for this criterion is linked to a qualitative estimation of the effort needed to reconfigure the facility.

In this context, two assumptions have been considered:

- for the following missions the Virtual Locker of Space Rider remains the same;
- the size of the facility must be optimized for the considered mission in order to not put into orbit extra mass.

The case of reconfiguration taken as illustrative is to pass from three smaller P/Ls to a single bigger one, considering that the boarded mass is the same for the two missions.

Three levels of complexity have been identified, here listed following an increasing value of effort, in terms of cost and time:

1. No intervention needed;
2. New configuration/new manufacturing;
3. New design and development.

The closed and the half-closed solutions fall back into the case 3, because of the second assumption: in fact, considering that the dimensions and volume of P/Ls can change from one mission to another, the Aluminium frame will change to fit the new configuration and so it should be re-designed and developed. For the open alternative the level is the second: it could be necessary to produce new panels to extend the available surface of contact for the P/Ls or to move the existing ones to reshape the plate, so that there is no redundant surface. The same happens for the fourth alternative, the no-structure one: in fact beam elements constituting the structure can be disassembled and reconfigured, or some new elements can be added if needed. If new elements, in both cases of panels and beams, are mass-produced new design and development are not necessary.

For this criterion, an exponential formulation is taken into consideration: calling x the level of complexity for the alternative in question, the score is assigned according to the function $f(x) = 2^{1/x}$. The exponent is the reciprocal of the level as to indicate that the higher is the level, the greater is the effort and so the less facilitated is the reconfiguration of the system.

The choice of employing such a formulation bases on the will of damping the discrepancy among the levels: in fact, since the second assumption reported above is applied, modification interventions should be realized anyway, unless payloads dimensions and encumber remain the same from one mission to another. At this level of the project it isn't possible to evaluate in a quantitative way the effort needed for the reconfiguration, so under this point of view it could be imprudent to significantly diversify the alternatives.

3.2.3 Integration Simplicity

The versatility that the facility shall have regards also the integration process: from one side, the integration of P/Ls into the platform, and from the other, the integration of the platform itself into the Cargo Bay. In this context, it can be a remarkable value the simplicity in these integration processes. Since the P/Ls mounting on the platform should be carried out by the company that designed and developed the facility, it is polite to assume that the entity in question is equipped with all necessary instrumentation and staff for the AIT process, so for this first analysis it is not relevant how this phase is eased and standardized by the configuration of the platform. The priority should be given to the integration of the facility into the Cargo Bay: in fact, it will be completed at the launch site, where Ground Support Equipment (GSE) and procedures should be standardized. The simplicity in the transportation from the developer company to the launch site shall be also taken into account.

For this reason, the "Integration Simplicity" criterion evaluates the level of complexity of the facility handling, as well as the standardization of GSE needed for testing and integration and of the interfaces with SR.

To rank the four alternatives following this criterion, a score is assigned to them as the sum of the following characteristics/needs:

- if the solution doesn't need external casing or particular supports during the transportation and the assembly, 1,5 score is assigned to it;
- if the necessary equipment for testing is standard (e.g. a plate), 2 points are added to the alternative;
- if the solution has plug-n-play interfaces for power and data, 1 point is added to it.

With this formulation, the situation is the following: all solutions are equipped with standard interfaces that allow a fast and simple coupling (e.g. USB), so they all start with a score of 1. The "Open" solution, like the "Closed" and the "Half-closed", can undergo testing on a standard surface and don't need any adapter or structural support, as the "Multi-beam" solution does as it was conceived: so the first three earn 2 points, while the last one does not. In addiction the "Open" and the "Multi-beam" need for an external casing for the transportation, because P/Ls are exposed to potential impacts or they can be accidentally moved from their correct position. The other two solutions bypass the problem due to their own configuration (they only shall be protected against contamination). For this reason, 1,5 point is added to "Closed" and "Half-closed". Results are resumed in Table 3.3

	Handling (+1,5)	GSE and procedure (+2)	Interfaces (+1)
Open		x	x
Closed	x	x	x
Half-closed	x	x	x
Multi-beam			x

Table 3.3: Integration simplicity score

3.2.4 Flight heritage of platforms with similar characteristics and configuration

Another way to evaluate the four alternatives is to compare them to existing facilities that carry out the same functions. The systems used for the comparison are those exposed in Chapter 1.

This comparison can be useful because even though this facility tries to be innovative from the production, integration and verification points of view, it can be a relevant value to have a similarity with something that is real and tested in an operative environment (i.e. Technology Readiness Level (TRL) 9).

To evaluate the level of similarity, three cases with increasing similarity are identified:

- new structure concept but same functionalities;
- same structure concept but different functionalities;
- same structure concept and same functionalities.

According to this kind of classification, the "Open" alternative results in being the only one that follows existing facilities both in the structure concept and in functionalities. In fact, both ELC and Bartolomeo have a plate shape and provide to P/Ls power and data. The "Closed" and the "Half-closed" solutions can be compared to Nanoracks internal facilities, respectively to BlackBox and to Nanode: this is true for the structure configuration but not for functionalities. Nanoracks platforms are equipped with fans that allows airflow in the payload volume; this capability is not expected for the systems under analysis. Eventually, the "Multi-beam" alternative, in spite of providing for functionalities that are common to different facilities (i.e. power management and distribution and data handling), it has a totally new structure concept and cannot be related to any of the existing and operative systems.

The formulation employed to evaluate this criterion is another time an exponential one: in $f(x) = 2^x$, x represents the level of similarity, so the higher it is, the better is the score. The use of exponential functions promotes the highlighting of differences among alternatives, allowing a suitable ranking, more than a linear formulation could do.

3.2.5 Volume allocation capability

With this criterion it is possible to measures how well the compartment volume is used: the employed parameter, in fact, is a combination of one value, showing the percentage of the compartment usable volume for P/Ls allocation to the total available volume of the considered location, with another one representing a measure of the relative expected mass of the alternatives. Assuming that the design of the structure maximise the available volume considering the compartment AIT constraints, this parameter evaluates the capability of the alternative to exploit the available volume and so to maximise the accommodation capacity.

On the other hand, everything that is put into orbit has a price: so it is advisable to reduce the unnecessary mass and to minimize the indispensable one. For this reason, also the bulk of the facility itself should be considered.

The employed formulation defines three levels of volume allocation capability, defined by using a fraction value of the compartment usable volume for P/Ls allocation obtained from the CAD models of alternatives, and assigns relative scores:

- up to 30%: 1;
- from 30% to 60%: 2;
- from 60% on: 3.

This grades are summed up with the score vector obtained by a pairwise comparison on the relative expected mass of the alternatives, shown in Table 3.4. Here, each solution in rows is compared to the one in the columns: the assigned score represents how much the alternative in the row is lighter compared to the one in the column (e.g. the "Open" solution is expected to be 2 times lighter the the "Close" one).

Expected Mass	Open	Closed	Half-closed	Multi-beam	**Score Vector**
Open	1	2	1,67	0,83	0,307
Closed	0,5	1	0,83	0,50	0,161
Half-closed	0,60	1,20	1	0,56	0,189
Multi-beam	1,20	2,00	1,80	1	0,343
Sum	3,30	6,20	5,30	2,89	1

Table 3.4: Pairwise comparison of the facility expected mass

3.3 Prioritization of Criteria

Criteria can have a different value according to the hierarchy of stakeholders that require them, so it is necessary to establish a priority for each criterion: a weight is assigned to each of them, to represent the relative importance and so to rank them. This process is resumed in the *prioritization matrix*, built through a pairwise comparison in which a value from 1 to 9 and their reciprocals is assigned to each criterion to indicate the relative importance of one compared to each others. The value 1 stands for "equal importance" and 9 for "of extreme more importance" [17], as shown in Figure 3.1.

1	Equal Importance
3	Moderate Importance of One Over Another
5	Strong or Essential Importance
7	Very Strong or Demonstrated Importance
9	Extreme Importance
2, 4, 6, 8	Intermediate Values
Reciprocals	Reciprocals for Inverse Comparison
1.1 - 1.9	When the elements being compared are nearly equal

Figure 3.1: Pairwise comparison scale by Thomas L. Saaty

Once the prioritization matrix is filled out, its eigenvector and eigenvalues are calculated to define the *priority vector*, which contains criteria weights and is used to assign final score to the alternatives. The priority vector is derived by the normalisation of the eigenvector for the maximum eigenvalue [17]. Results are shown in Table 3.5.

As it can be seen from the priority vector, the first two criteria turn out to be sensibly more important compared to the other three. This reflects the drivers of the project and the objectives that the system should achieve. The last three criteria are anyway essential in the evaluation of the alternatives, since they reflect significant attributes of the design. The adaptability and reconfigurability criteria are given the same level of priority (i.e. "1") because they evaluate the same capability from two points of view: the first quantifies how much the facility is multi-purpose while the second one how much it is complex to adapt it to the different purposes. They have equal importance since having a versatile platform is as essential as allowing simple modification interventions aimed to adapt it to different missions.

Prioritization Matrix	ADAPT	REC	INTS	FLIH	VOL	**Priority Vector**
ADAPT	1	1	3	2	2	0,3053
REC	1	1	2	3	2	0,2956
INTS	0,33	0,5	1	2	1,5	0,1611
FLIH	0,5	0,33	0,5	1	1	0,1115
VOL	0,5	0,5	0,67	1	1	0,1264
Sum	3,33	3,33	7,17	9,00	7,5	1

Table 3.5: Pairwise comparison matrix for prioritization of criteria

3.4 Synthesis and Results

Once alternatives, criteria and their prioritization are unequivocally defined, scores can be assigned to fill the decision matrix (Table 3.6): it represents the *Synthesis* of all the considerations and elements showed so far. The overall score, which decides the final ranking of the alternatives, is calculated by multiplying normalized scores by the criterion weight, and summing up the results for all criteria per alternative. Normalized scores are obtained by dividing each grade for the sum of grades of all the alternatives for the particular criterion, so that the sum of scores of all alternatives for each criterion is 1 [17]. Table 3.7 shows normalized scores and the resulting final ranking of the alternatives.

	Alternatives			
Criteria	Open	Closed	Half-closed	Multi-beam
ADAPT	13	1	13	13
REC	1,41	1,26	1,26	1,41
INTS	3	4,5	4,5	1
FLIH	8	4	4	2
VOL	3,31	2,16	2,19	3,34

Table 3.6: Decision Matrix

	Priority Vector	Open	Closed	Half-closed	Multi-beam
ADAPT	0,305	0,325	0,025	0,325	0,325
REC	0,296	0,264	0,236	0,236	0,264
INTS	0,161	0,231	0,346	0,346	0,077
FLIH	0,112	0,444	0,222	0,222	0,111
VOL	0,126	0,301	0,196	0,199	0,304
	Final Score	0,302	0,183	0,275	0,241
		I	**IV**	**II**	**III**

Table 3.7: Normalized score and final ranking

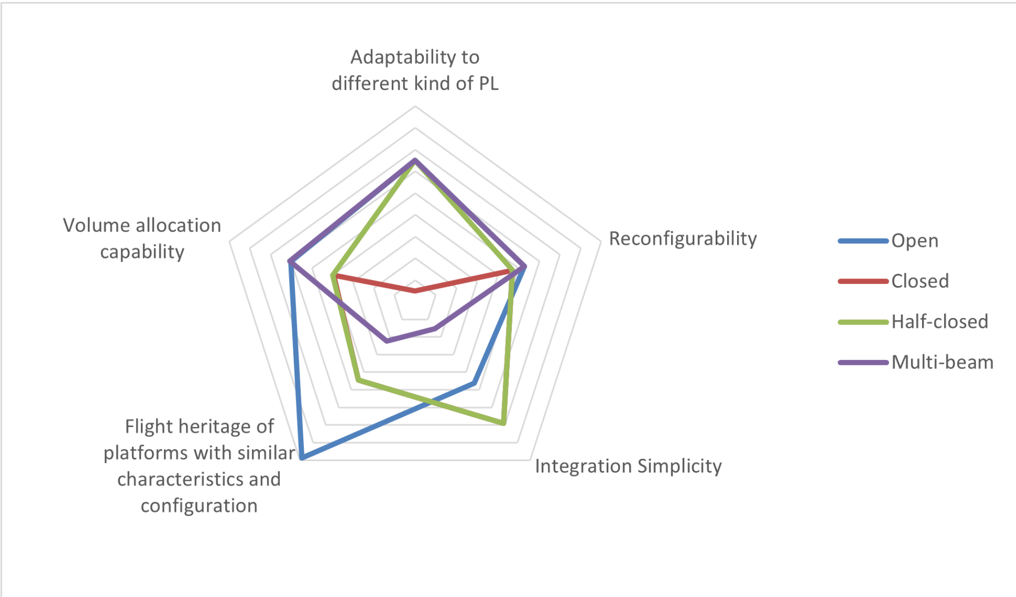

Figure 3.2: Final results

As the final ranking shows, the "Open" solution results in being the most suitable one, being followed by the "Half-closed", the "Multi-beam" and finally by the "Closed" alternative. The obtained results are influenced by the choice of attributes evaluated by the criteria, therefore by the stakeholders demands, but also by criteria relative importance, i.e. the prioritization. For this reason, in order to increase the awareness in choosing a particular solution for the facility, robustness of the results should be assessed through a sensitivity analysis, explained in Section 3.5.

Another representation of the final score is shown in Figure 3.2: here, the higher is the alternative grade, the bigger is the surface enclosed by the corresponding pentagon. This graphs also helps in identifying which solution better satisfy a certain criterion. As it is expected to be, the flight heritage of the "Open" solution is enhanced by the fact that most of existing facilities have a *plate* configuration, as the alternative does. On the other hand, its integration simplicity is lower than that of the "Closed" and the "Half-Closed", since the configuration doesn't allow to move the integrated facility without providing for a casing. Being the "Open" solution the winner of this analysis, it can be an improvement of the design in its future development to plan a dedicated casing for the facility transportation from the integration site with P/Ls to the launch one.

Considering the *Volume allocation capability* criterion, the alternatives "Closed" and "Half-closed" result penalised because of their expected mass, being higher than others due to the presence of lateral sides and of the upper one (for the "Closed"), but also for the volume of P/Ls they can accommodate given a certain volume with limitations to respect (i.e. the Virtual Locker). It should be said, though, that the presence of lateral surfaces extends the attaching capability of the facility. Therefore, if the P/Ls dimensions and needs allow it (e.g. the necessity of a FOV), it could be possible to arrange more than one layer of P/Ls by attaching them to the lateral surfaces or to the upper one (for the "Closed"). In this way, the available volume, though reduced compared to the "Open" or "Multi-beam" one, could be used in its totality.

3.5 Sensitivity Analysis

As introduced before, this kind of analysis turns out to be necessary to assess the sensitivity of the trade-off from the point of view of both the criteria relative weights (i.e. prioritization) and the alternatives score for each criterion. The identification of most critical criterion, from one side, and the one of the most influencing parameters score, from the other, allows to review decisions taken during the analysis and so to interpret results under a more aware concept.

In the following tables alternatives are indicated with a number from 1 to 4, being 1 corresponding to the "Open" solution and so on, following the order of presentation used in Section 3.1.

The first step in this analysis regards the identification of the most critical criterion, which can be defined as the one for which a small change in its weight could entail a different final ranking of the alternatives and cannot correspond to the one with the highest weight [17]. The *smallest change* implying a change in the alternatives ranking is identified in two ways. The first is in absolute terms: in Table 3.8 values corresponding to minimum change in criteria weight so that the couple of alternatives reported in the first column mutually change their existing ranking positions are shown. Minimum changes are expressed in absolute value, so the change can correspond to both a decrease or an increase of the criterion weight.

Cells in green report the smallest value of each criterion: however, these values may correspond to a change in the criterion weight of more than the weight itself. For this reason, the second way to evaluate the minimum changes is by relative values: it results necessary to point out which changes are feasible and which overcome the 100% and are hence not feasible (i.e. pointing out the robustness of the criterion).

By considering absolute values it may seem that for three of the five criteria, alternatives 1 and 3, which are respectively at the first and the second position of the ranking, result the most sensible. Other apparently feasible values are registered for the couple 2-4 for the adaptability criterion and for the couple 3-4 for the integration simplicity. However, by computing absolute values, whose results are shown in Table 3.9, it can be noticed that the only two feasible changes are those that regard the couple 2-4 for the adaptability criterion and the 3-4 for the integration simplicity.

The smallest percent amount by which the current value of the criterion weight must change, such that the existing ranking of the alternatives will change is the *criticality degree* [18]. In the case under study, these percentages are 64% for the adaptability and 76% for the integration simplicity: the "Multi-beam" alternative will switch its position with the "Closed" in one case, with the "Half-closed" in the other one. The reciprocal of the criticality degree represents the criterion *sensitivity coefficient*; if the criticality degree is infeasible (i.e. the minimum change for the criterion exceeds the 100% of its weight), then the sensitivity coefficient is set equal to 0 [18]. Coefficients for the current analysis are reported in Table 3.10.

As it can be seen, the most sensitive criterion turns out to be the one with the highest weight, i.e. the Adaptability to different kind of P/L; the Integration simplicity criterion also has a non-zero sensitivity coefficient. This can be associated to the fact that for the two criteria at issue, the score is identical for more than one alternatives: in fact, despite the four solutions are based on different configurations, they have some properties in common. Overall, being three out of five criteria completely insensitive to changes, the analysis can be considered robust from the point of view of the assignment of criteria weights.

	Criteria				
$A_i - A_k$	ADAPT	REC	INTS	FLIH	VOL
1-2	0,397	4,130	1,033	0,536	1,174
1-3	Inf	0,945	0,236	0,123	0,274
1-4	Inf	Inf	0,392	0,181	4,780
2-3	0,306	Inf	1990	Inf	43,418
2-4	0,196	2,037	0,218	0,529	0,515
3-4	Inf	1,147	0,123	0,298	0,296

Table 3.8: Minimum absolute change in criteria weights

	Criteria				
$A_i - A_k$	ADAPT	REC	INTS	FLIH	VOL
1-2	130	1397	641	481	929
1-3	Inf	320	147	110	217
1-4	Inf	Inf	244	162	3781
2-3	100	Inf	1235526	Inf	34350
2-4	64	689	135	474	407
3-4	Inf	388	76	267	234

Table 3.9: Minimum change in criteria weights in percentage

ADAPT	**REC**	**INTS**	**FLIH**	**VOL**
0,016	0	0,013	0	0

Table 3.10: Sensitivity coefficients

Since this early phase of the design has often to cope with lack of data, in order to assign the score per criterion to the alternatives, qualitative evaluations and approximations have been applied, as well as some assumptions have been admittedly used to define boundary conditions and constraints of the facility use case. For this reason, a sensitivity analysis of the assigned scores is performed, so that the robustness of the alternatives ranking can be assessed and results uncertainty discussed.

In order to perform this analysis, threshold value $\tau_{i,j,k}$, defined as the minimum change that has to occur on the current value of alternative i score for the criterion j such that the current ranking between alternatives i and k will change, shall be evaluated [18]. For the reason explained before in the context of the sensitivity analysis of the criteria weights, threshold values are evaluated in relative terms and results are shown in Table 3.11. What is to be searched for is the minimum value per criterion (represented by green cells in the Table), hence corresponding to the criticality degree of the alternative. It can be noticed that the most sensitive alternative results the number 1, i.e. the "Open" solution, also the first in the final ranking: in fact, for all the criteria, a more or less significant change in the assigned scores, will exchange its position with the one of the alternative 3 (i.e. the "Half-closed", namely the second classified). The last one results in being as sensitive as the alternative 1, having feasible threshold values for all criteria. A similar situation occurs, but only for some of the criteria, for the couple of alternatives 2-4 and 3-4.

	Criteria					
Alternative i	ADAPT	REC	INTS	FLIH	VOL	Alternative k
1	70,98	106,59	172,51	105,00	152,84	2
1	25,00	30,91	56,57	37,25	53,942	3
1	51,24	64,80	106,95	65,54	107,92	4
2	922,68	119,24	115,17	210,00	234,72	1
2	752,73	100,58	105,06	203,64	214,55	3
2	510,01	67,91	63,87	143,65	149,42	4
3	25,00	34,58	37,77	74,50	81,59	1
3	57,90	100,58	105,06	203,64	211,31	2
3	30,83	42,64	41,21	97,01	98,378	4
4	51,24	64,80	320,85	262,15	106,86	1
4	39,23	60,71	287,02	287,30	96,333	2
4	30,83	38,12	185,19	194,02	64,399	3

Table 3.11: Threshold relative values per criterion

Sensitivity coefficients, defined once again as the reciprocal of the criticality degree, are shown in Table 3.12: the alternatives 1 and 3, the first two positions of the final ranking, are confirmed to be the most critical ones.

By observing solutions final ranking, represented in the last rows of Table 3.7, this kind of result could be expected: the first and the second solutions don't have, in fact, a significantly different grade. A feasible explanation to that can be linked to the fact that the differences between the two alternatives differences aren't properly evaluated with the chosen criteria. The main difficulty of the study indeed, has been not being able to employ a quantitative and detailed assessment also linked to the fact that at this early level of the design physical characteristics and performance are not well-defined.

	Criteria				
Alternatives	ADAPT	REC	INTS	FLIH	VOL
1	0,04 (3)	0,032 (3)	0,018 (3)	0,027 (3)	0,018 (3)
2	0	0,015 (4)	0,016 (4)	0	0
3	0,04 (1)	0,029 (1)	0,026 (1)	0,013 (1)	0,012 (1)
4	0,032 (3)	0,026 (3)	0	0	0,015 (3)

Table 3.12: Sensitivity coefficients

3.6 Considerations and Future Work

Trade-off analysis results to be a useful tool in the decision making process regarding the configuration and the structure of the facility under study. Without it, pro and cons of each possible solution wouldn't have been evaluated, therefore the study would have been incomplete and approximate.

Even though sensitivity analysis results declare a criticality in two of the five employed criteria and between the first two classified alternatives, the conceptual design of the platform will continue considering the "Open" solution, i.e. the winner of the trade-off, as the chosen configuration.

Future developments of the study may regard the employment of quantitative attributes to evaluate the alternatives performance and characteristics. To do this, alternatives should be defined in more detailed way, as a result of an iterative process of a more and more specific functional analysis, derivation of requirements, trade-off, up to the definition of equipment components and parts. Therefore, the current analysis may be reviewed in sight of new details and constraints arriving both from the vehicle and from the P/Ls to accommodate.

Chapter 4

Platform Conceptual Design

In this Chapter, guidelines for the design of the facility are given. According to results collected during the preliminary study and the trade-off analysis, a hypothetical configuration for the "Open" alternative is presented with the support of a CAD project, in which three payloads are placed together with a power management unit and an on-board computer.

Therefore, considering requirements and constraints of the platform, subsystems equipment to be installed on it are defined and identified with some COTS components, selected after a literature search.

Finally, a preliminary evaluation of the platform mass budget is performed. The electrical power and data usable by the facility are constrained by the SR vehicle resources; in addition, lacking of information about the data received by the payloads that should be processed and sent to SR OBC doesn't allow the evaluation of the data budget. For these reasons, the estimation of the budgets for power and data are postponed to an advanced phase of the design.

4.1 CAD

According to MIS001 and to CON001 requirements, the platform structure shall have modularity and adaptability properties. Trying to satisfying these demands, the proposed concept is thought as a set of a main frame, extendable in one dimension, and some panels, bolted to the frame and in a variable number, according to the necessary extension for the attaching of all payloads.

Figure 4.1 shows a possible concept of the principal structure: as it can be noticed, it is composed by a drilled baseplate to be bolted to the compartment plate, and by three attachments, extendable along their principal axis direction through a scrolling mechanism. In case the extension is not necessary, the lengthenings are retracted inside of the structure and fastened. Employing this configuration, the

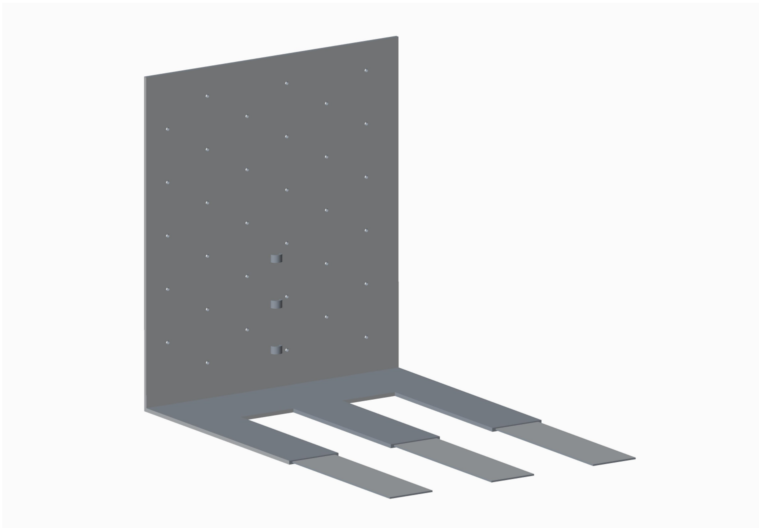

Figure 4.1: Aluminium frame

minimum length of the frame is equal to the half of the compartment corresponding dimension. By completely pulling out the lengthenings, all the compartment length is covered. Baseplate dimensions make that it could cover almost the entire interface plate of the compartment considered for this study, but due to its size, it can be easily installed on other Lockers.

The structure may be manufactured in Aluminium alloys to combine a limited density with strength and stiffness properties of Aluminium. Since the baseplate will be also the allocation site for the subsystems equipment of the facility, some tracks for the wiring fixation should be considered on it (e.g. welded semicircular ties), together with fixation points for thermal blankets.

For the detailed sizing of thicknesses and attachments width, a structural analysis is needed to identify the maximum sustainable load for the structure and the optimal mass distribution. This step may be performed during a future progress of the design.

The structural subsystem is completed by panels that may be composed by composite material and produced by a rapid prototyping technique. They allow the modularity of the platform since they can be added or removed to increase or decrease the allocation capability of the system. In the proposed solution, they are disposed as shown in Figure 4.2, so in a 3 x 2 configuration, which covers the entire volume of the compartment. A feasible shape for the panels is the one shown in Figure 4.3: it has male-female joints for the coupling with other panels and with the structure and holes for a fixation with bolts.

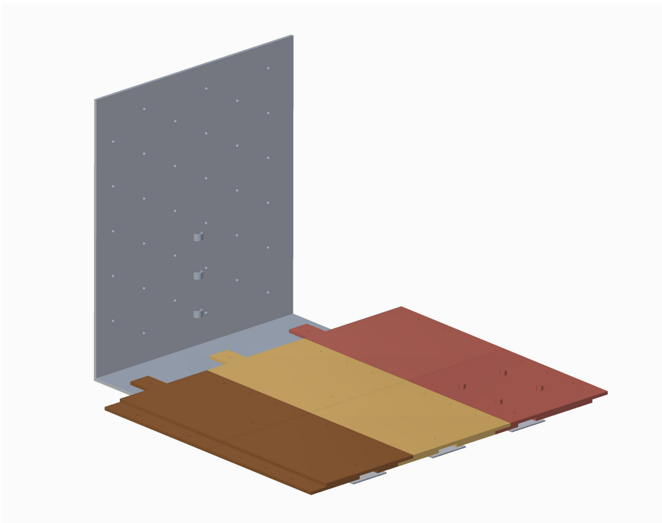

Figure 4.2: Configuration with six panels

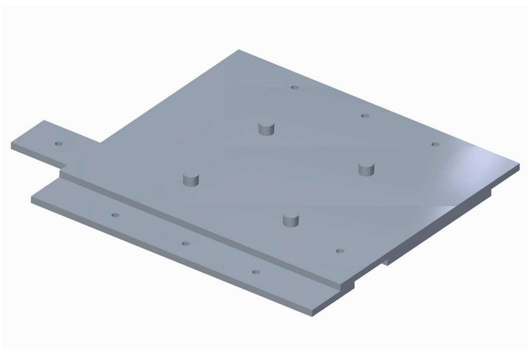

Figure 4.3: Composite panel

The chance of employing additive manufacturing technologies for the production of parts of the facility (in this case, panels are considered, but their applications can be an option for the manufacturing of the main frame, too) bases on different factors that makes it a valid option, considering requirements and constraints of the project, especially those regarding logistic and operations aspects [19]:

- cost: small and medium production batches can be manufactured at comparatively low costs;
- time: since products are made directly from the CAD model, production time is reduced by cutting down on the production development step, supply chain, and dependence on inventory;
- product complexity: products geometry isn't limited by practical constraints, it can perfectly match the one designed with the CAD model;
- prototyping: extremely useful for prototyping and evaluating product concepts since it allows for design changes and iteration;
- post fabrication processing: limited to no post-fabrication processing is required, depending on the technique and material used.

There are different options for both the material and the manufacturing technique: composite materials are here considered and presented, together with suitable techniques for their manufacturing. The choice of suggesting a composite material relies on its own characteristic of low density with the possibility of tailoring it to have high stiffness and high strength, e.g. by adding fibre reinforcement. Some of the rapid manufacturing techniques are:

- *Selective laser sintering/melting (SLS/SLM)*: it can be applied to a polymer or metallic powder, whose solidification is obtained by heat input from a laser, causing a solid state sintering or melting of the powder material. The basic process of SLS uses a pure polymeric powder, but a ceramic material can be added to improve the mechanical properties [20];
- *3D printing*: this method does not require a laser because the powder cohesion is ensured by a binder deposition layer by layer made by a printer and after each layer the binder is cured;
- *Laser cladding*: it injects the powder directly in the laser beam spot through one or more injection nozzles (if several nozzles are used, different materials can be used in the same spot).

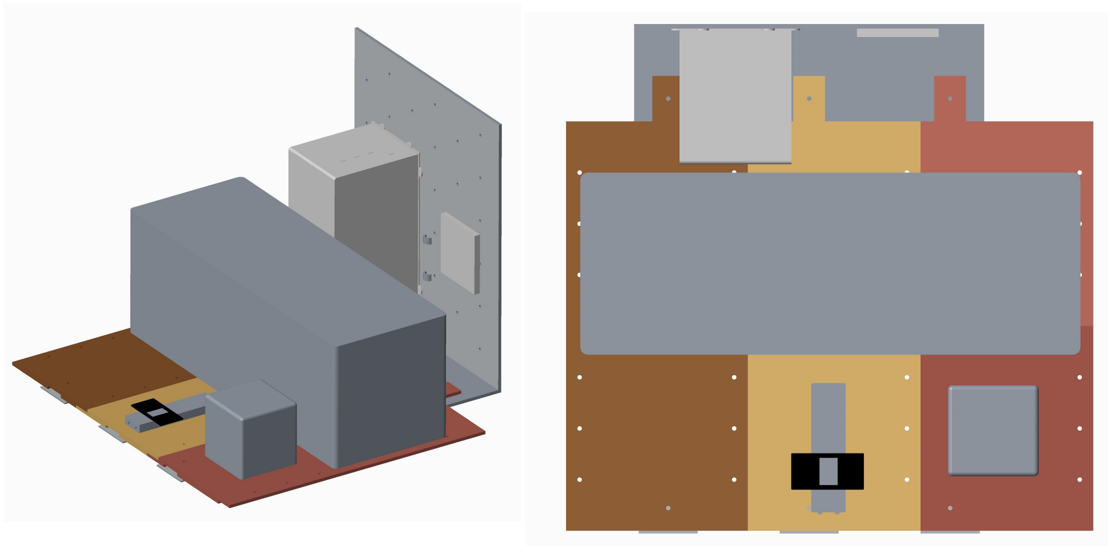

Figure 4.4: Views of the complete configuration

Since additive manufacturing allows the rapid modification of the design of the produced part, it can be an advantage to apply it for the production of panels, given that payloads dimensions and attachments may change from one mission to another, so the panel design may change according to payloads necessities. In fact, it is possible to add or remove structural supports and coupling sites as long as the payload needs them. In this way, the reusability of the facility is linked to the main frame, that may remain the same also if the compartment and/or the payloads changes, while panels design may be easily modified (changing its CAD model) and their production may occur in relatively limited time and cost.

For the case study taken into consideration, a possible configuration of the facility integrated with three payloads of different dimensions and purpose and equipped subsystems (i.e. power management and distribution unit and on board computer), is shown in Figure 4.4.

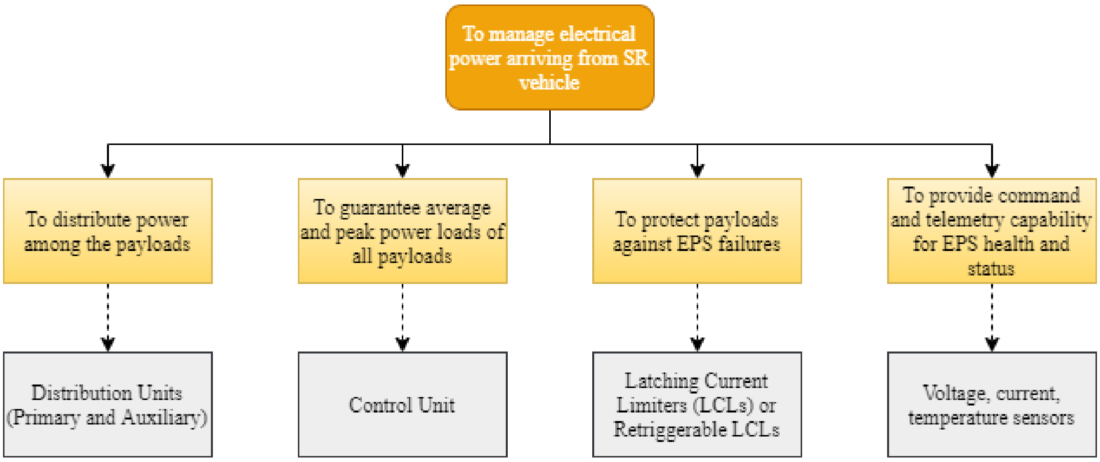

Figure 4.5: EPS functions and equipment

4.2 Definition of Subsystems

As mentioned before, subsystems to be installed on the facility are presented and a proposal of COTS components suitable for the analyzed case study is made. These components have been selected after a research on different websites of companies specialized in space equipment manufacturing. Criteria employed for the selection are first of all the flight heritage, considering only components and systems that have already successfully employed in a LEO mission, then, the compatibility with the vehicle constraints and its operations.

Whether the particular mission does not require the installation of one or more subsystems, they can be removed from the facility baseplate, therefore the payloads can be directly linked to the compartment interfaces. In this way, the modularity and the scalability of the system are ensured also from the functionalities point of view: the facility complexity can vary from a simple structural support to a complete system able to provide power management, data handling and thermal control.

4.2.1 Electrical Power Subsystem

As it has been derived from the functional analysis (Section 2.4), the functions that the Electrical Power Subsystem should accomplish can be summarized in the tree of Figure 4.5, where components that would carry out these functions are also reported (grey frames).

As it can be noticed, there are four main functions for the EPS, whose final goal is to provide electrical power to installed P/Ls: first of all, it has to distribute power arriving from the vehicle EPS among them, dividing it so that each payload power demand is satisfied (i.e. the second function), considering both situation of average and peak loads; then, the subsystem has to protect P/Ls from its failures, in particular from current surges, that would compromise the P/Ls health; finally, it is necessary to monitor the EPS status, so to collect telemetry and to eventually receive commands from the ground.

Since data about P/Ls duty cycles and operating modes are not available in this phase of the project, as well as detailed information on the vehicle capabilities, some assumptions are made, to analyse the compatibility of components to the system and the mission. These ones are:

1. one 28V power line arrives from SR vehicle EPS and connects to the facility EPS through one connection point;

2. two buses per payload are considered (one primary and one auxiliary), so for the case study configuration, six lines are necessary;

3. the maximum required power by all three installed P/Ls is of 410 W;

4. power regulation is to be performed by the facility EPS.

The selected EPS equipment proposed for the case study is the *Starbuck-Mini* by AAC Clyde Space, a power conditioning and distribution unit with a modular design approach that enables tailoring by employing flexible add-on modules to meet the required number of interfaces for payloads. All information about it has been learned from the datasheet available at *https://www.aac-clyde.space/*.

Starbuck-Mini is composed by COTS and radiation hardened components that enhance its reliability. It is designed for 5 to 7 years life in LEO, so the MIS003 requirement is met and can manage up to 1500 W of power, so the assumption number (3) reported above is accomplished, too. Voltage and operating temperature ranges are compatible with the vehicle power and thermal services, being 22-34 V the first one, and -30°C to +60°C the second one. Interfaces for telemetry and telecommand are CAN or RS422 serial interfaces. In the baseline configuration of the subsystems there are 4 primary bus high power outputs, 12 primary bus nominal outputs and 12 secondary bus outputs; therefore, it results suitable for the case study mission, according to the assumption number (2). All the outputs have an individual protection made by either a latching current limiter (LCL) or a retriggerable latching current limiter (RLCL), which are switches that provide temporized protection, controlled inrush and limited overcurrent and give the possibility to restart the loads that suffered temporary failures [21].

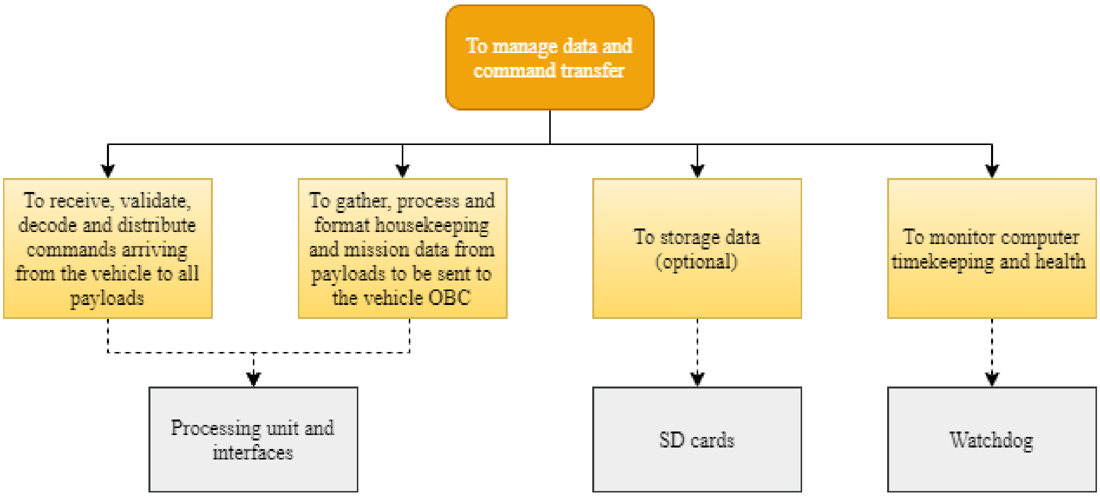

Figure 4.6: Data handling subsystem functions and equipment

4.2.2 Data Handling Subsystem

Functions that this subsystem should perform are shown in Figure 4.6, together with components that are responsible for them (grey frames). The first and the second ones starting from the left regard the communication between the SR vehicle OBC and the payloads: in fact, the facility data handling subsystem shall be installed to collect and transfer P/Ls mission data and telemetry to SR OBC and then to the ground segment (after an eventual processing), but also to manage the distribution of commands among P/Ls. To perform such functions a processor is needed which interfaces from one side and possibly with a single connection point to SR OBC, and from the other one to installed P/Ls. According the last ones design, interfaces can be of various type and purpose.

If P/Ls require it, the possibility of data storage should also be considered, therefore, a complete subsystem shall have SD card slots or other mass storage systems. Anyway, all data generated by payloads is also stored by the SR for delivery after the end of the mission on a storage disk recovery. The last function that the system should perform is the monitoring of the computer health: this can be done through a watchdog timer.

The online research for the ideal component to be installed on the facility provided as result the *ISIS On board Computer* (IOBC) by ISISPACE, a flight proven processing unit with heritage since 2014. Information on it has been collected on the official website *https://www.isispace.nl/*. The IOBC is equipped with a high performance ARM9 processor with a clock speed of 400 MHz and various standardized interfaces, among which 2 UARTs allowing RS422 serial interface with the vehicle. SR also provides for a SpaceWire connection that needs a Micro-D interface (9 pins): the proposed component is fitted out with General Purpose Input/Output pins (GPIO) that can be purposed to this kind of connection. It has 2 SD card slots for mass data storage many other kind of interfaces (e.g. an image sensor interface, dedicated debug UART; an external watchdog is present, too. Operating temperature range is compatible with the SR MPCB one, being -25°C to +65°C.

All these characteristics make the IOBC a good candidate for the data handling subsystem of the facility under study.

4.2.3 Thermal Subsystem

SR vehicle can ensure the thermal control of the MPCB within the temperature range of 15°-35°C and a thermal stability of +3°/-3°C. In case of P/Ls to be installed require a tighter thermal control than that offered by the vehicle (e.g. for biological and optical payloads), some passive thermal control devices should be integrated in the platform to maintain the necessary temperature limit. As explained in Section 4.1, the tailoring of panels allows to include fixation points for MLI blankets in the design of the panel itself: if the payload doesn't need a field of view while it requires a precise thermal control, it can be completely covered with thermal blanket; whether the payload needs a view capability on external environment, blanket may cover the panel only, to guarantee a certain emissivity value. MLI may be also used to insulate other subsystems components, i.e. the on board computer and the power management unit, therefore fixation points should be considered also on the aluminium baseplate.

In order to reduce the thermal coupling at selected interfaces thermal washers can be installed, while thermal fillers can be employed to improve the thermal coupling at selected interfaces. A thermal analysis, which can be performed as an evolution of the design, when more detailed information about payloads will allow to identify most sensible points of the structure where such thermal control methods should be applied.

4.3 High-level Mass Budget

The design of a spacecraft is largely influenced by the available mass budget: so it is the design of the facility for payloads accommodation. Usually, in a project phase like the one carried out in this study, there are not any detailed information about the components weight that will compose the system, so it is necessary to estimate the mass to be dedicated to each subsystem as a percentage of the spacecraft dry mass, i.e. the total mass excluding the fuel weight. For the system at issue, there is not a real dry mass since no propulsion system, and so fuel, is

	Percentage of the facility total mass [%]	Expected resulting mass [kg]
Structure	25	5.6125
Thermal Control Subsystem	5	1.1225
Electrical Power Subsystem	20	4.49
Data Handling Subsystem	10	2.245
Payloads	40	7.184
Facility total mass	100	22.45

Table 4.1: Estimation of subsystems mass

expected to be installed on it. However, it may be a proper assumption to consider the dry mass as the total mass of the platform and express the subsystems mass as a percentage of it.

According to the method proposed in *Space Mission Analysis and Design - Third Edition*, by J.R.Wertz and W.J.Larson [14], the payload weight is typically less than half of the dry weight and may be as little as 15% of the dry weight. Since at the moment, the only almost final data is the selected P/Ls mass, it is possible to use this percentage to calculate the total facility mass of first iteration. Being the P/Ls the most substantial part of the integrated platform, a percentage of 40% is assumed for this calculation. Basing on the design maturity, the employed method proposes a margin that varies from 5% to 25%: for this preliminary study, it is rational to assume a margin of 25%. Applying these considerations, the total mass of the facility integrated with the 3 selected P/Ls results to be of 22.45 kg. From this first evaluation, expected mass of the installed subsystems and of the structure can be estimated: employed percentages and absolute obtained results are reported in Table 4.1.

The selected equipment for the power management and data handling subsystems has been chosen also to accomplish these mass values: in fact, the main body for the first has a mass of 3.3 kg, while for the second is 100 g. To these values, wiring mass should be added: as first estimation, it can be rounded to the 5% of the dry mass, i.e. the facility total mass.

In order to evaluate the mass of the structure, considering both the Aluminium frame and the composite panels, and the one of MLI blankets needed to cover the entire surface (i.e. the baseplate and the surface made up of 6 panels), values of density found in literature are employed together with surface measurement based on the CAD model shown in Section 4.1. The most of Aluminium-Lithium alloys employed in space structures has a density that varies from 2.63 to 2.72 g/cm^3; therefore, a density of 2.70 g/cm^3 is assumed as an average value [22]. For the composite panels a density value of 1.22 g/cm^3 is assumed for a polycarbonate composite with a calcium carbonate filler with a weight percentage of 10% [23].

		Calculated Mass [kg]
Electrical power subsystem	Power management unit	3,3
	Wiring	1,12
Data handling subsystem	On-board computer	0,1
	Wiring	1,12
Structure	Aluminium frame (2,70 g/cm^3)	3,72
	Composite panels (1,22 g/cm^3)	3,17
Thermal control subsystem	MLI (1,2 kg/m^2)	0,52
Payloads		7,18
Facility Total Mass		20,23

Table 4.2: First iteration mass calculation

For the MLI, it is considered a weight of 1.2 kg/m^2 for a 0.5 cm-thick blanket made of Aluminium foils and fiberglass spacer [24].

As it can be noticed, the resulting mass calculated employing values reported in Table 4.2, is 20.23 kg: this value falls with a considerable margin (almost 10%) into the budget estimated with percentages (Table 4.1). Watching at the single subsystems mass, the expected values are higher than the calculated ones for all subsystems expect for the structure: in this context, a more deepened analysis could lead to an optimization of thicknesses and of the composite material composition, so that the mass of both frame and panels would be reduced to minimum, certainly in compliance with load requirements.

Chapter 5

Considerations on Feasibility

As conclusion of this study, it is important to identify which could be potential problems and challenges connected to the development and the realization of the project at issue. If from one side these challenges put a limit on the system versatility and usability, from the other one represent a chance of innovation and employment of alternative solutions that would outdo those limits.

Since, as declared at the beginning of this report, the facility preliminary design has been performed by employing SR vehicle as use case for the platform first application, it is important to analyse its compatibility with the vehicle and the operations. The last discussion is done basing on current available information about SR configuration and operations. Hence the current chapter represents a collection of considerations done so far that have already partly mentioned in previous sections and are here recalled and deepened.

5.1 Main technological challenges

Requirements of modularity and multipurpose usability introduce some technological challenges that may influence the facility design. These ones mainly regard:

- adaptability to different missions and to different space systems in a short time and with limited re-checks;
- scalability in terms of installed subsystems and enabled functionalities;
- intervention time reduction for modification and verification;
- operational life with limited intervention as much as possible.

In performing the trade-off analysis the concept of *adaptability* is employed as an evaluation criterion of different alternatives from the point of view of the payloads that can be accommodated. In fact, to be *adaptable to different missions* entails that the payloads to accommodate could be of many different kinds (e.g. optical, biological, for the the study of radiation environment, etc.) and hence could demand for various capabilities (e.g. FOV, accurate thermal control, pressurized/non-pressurized environment). Different capabilities could imply different concepts for the facility structure itself: therefore, to reuse the same facility for different missions without radically modifying its configuration means to put a limit on the type of P/Ls that can be accommodated. As it has already been declared, the evaluation of the adaptability criterion in the trade-off analysis has been performed considering a series of P/Ls candidate for the facility first application: clearly, the seven considered candidates do not cover the entire variety of P/Ls that can be interested to fly on SR vehicle, but it is used as a significant representation of it. Therefore, however broad the target may be, it is limited by practical reasons, i.e. the adaptability cannot be ensured to whatever payload.

For what concerns the adaptability to various space systems/vehicles, the proposed design considers to employ standard interfaces, both mechanical and functional, so that the possibility to be compatible with other systems is higher. If not, for instance if equipment of one or more subsystems were not suitable, the possibility to change it maintaining the same structure may be considered. In this way, re-verification activities from one mission to another may be faster and simpler. The employment of COTS components also contributes to the speed of these activities, since they are already qualified for space applications.

An analog consideration can be done for the scalability concept: a structure like the one of the proposed solution allows to easily install or uninstall subsystems components, according to functionalities needed by the particular mission. This option regards both units like the on-board computer or the power management one and the thermal control equipment like the MLI or other insulation devices as well as active components. The last ones employment clearly increases both the complexity of the system and its mass, but can add an important functionality, allowing the accommodation of most sensible payloads, such some kind of biological experiments. Regarding the data handling subsystem, as previously announced, it may be composed by the on-board computer only if installed P/Ls require one of more of its functions, i.e. the data pre-processing, the data storage, the decoding of commands. Otherwise, the simple connection between the vehicle on-board computer and the P/Ls may be considered, so that the data handling subsystem decreases to only wiring and cables necessary for the linking. In the last case, data processing and storage capabilities of the vehicle (if available) should be considered.

In most cases, increasing the system complexity may mean to lengthen the duration of activities aimed at the verification of it. Therefore, the simplicity of parts constituting the facility results to have a key role in the time reduction for both verification and modification interventions. Concerning the structure of the system, it can be said that the standardization of components, i.e. the employment of parts, like the panels, that can be "mass produced", enhances this time reduction. Rapid prototyping plays a fundamental role in this process: once the basic model of the panel is completed and successfully verified, it will be sufficient, if needed, to modify the CAD model with adjustments necessary to accommodate the payload, such as adaptors or supports, and to print it. A more detailed analysis could state that in order to test the modified component, simulation activities are sufficient to verify it, therefore shortening verification process.

The system complexity is largely influenced by the electronic parts technology and in some cases, it increase exponentially with the employment of some devices, i.e. Field Programmable Gate Array (FPGA) and Application Specific Integrated Circuit (ASIC) [25]. COTS components employment may overstep the inherent complexity of these devices if they are embedded into a complete and ready to use system, already verified and qualified, e.g. the power management and distribution unit.

If the choice of components falls on parts that have an operative life at least as long as the time they are expected to be employed (i.e. for the use case, six missions over six years), maintenance interventions on them shouldn't be necessary. In this way, they could regard only the structure of the facility or the replacement of cables, joints and structural supports.

5.2 Compatibility with the system and operations

SR vehicle requires that payloads and experiments it is expected to bring into orbit, are designed meeting some safety constraints that the users/developers should assess in a systematic manner from earlier phases of their projects. In doing so, they have to identify any eventual hazards and to classify and verify them at each payload handling phase, including landing, recovery and maintenance.

Safety requirements mostly concern stress corrosion, flammability, off-gassing and toxic analysis, forbidden materials, electrical, electronic and electromechanical parts, as well as pressure vessels and batteries. All these requirements are based on different ECSS Standards. Since the current study is aimed to an high-level design, the compliance with the requirements at issue cannot be already verified in detail, but the proposed solutions for both the structure and the subsystems have been chosen by evaluating, at least broadly, also their compatibility with the vehicle.

Another aspect to consider regarding payload lifecycle, is the standardization of its ground and flight phases, being the last one an objective to reach in order to allow the optimization of the effort needed to the preparation of the mission. Beside the standardization of the interfaces between the payload (i.e. in our case, the facility) and the vehicle, there are also a timely definition of launch date and frequency, and the standardization of the ground equipment. All these factors should be taken into account during the facility design and have been partly considered in this preliminary study either as yardstick in trade-off analysis or as selection parameter in the choice of components. It must be highlighted that one of the advantages of developing such a facility for the payloads accommodation relies on the possibility to integrate and verify it in the developers infrastructures and to transport to the launch site a system already tested and ready for the launch (clearly excluding the integration activities of the platform with the vehicle cargo bay).

Finally, the compatibility of the platform with the operations timeline shall be verified. Despite SR vehicle allows a late access option for payloads which requires it, it is reasonable to suppose that this possibility will significantly increase the operations cost, therefore, it is to consider only if strictly necessary (e.g. when the payloads are biological). In all other cases, the time between the hand-over to launch facilities and the launch event must be considered in the payloads and the facility operative lives account, as it could last some weeks or even months. However, this aspect of compatibility mainly regards the payloads rather than the facility: in fact, the last one will be designed to be operative for a much more long time than a SR mission nominal duration, since one of its distinctive characteristic is to be reusable with the objective to employ it for at least six missions.

Conclusions

This study has allowed to investigate possible solutions for a payloads accommodation facility to be installed on space systems, like the SR vehicle. The platform at issue provides structural support, power management, data handling and thermal control to different types of payloads, such as microgravity experimentation, Earth observation, radiation environment study, etc., together with all the other functionalities that the particular payload requires for the accomplishment of the mission.

The constraints on which the design is based on are those of modularity, scalability of installed subsystems and reusability. According to these requirements and to others that ensure the above mentioned functions, four solutions have been identified and compared among each other through a trade-off analysis, whose results declare as the optimal alternative the one formed by an extensible frame structure, completed with some 3D-printed panels. The last ones number depends on the accommodation surface necessary dimensions in order to locate all the expected payloads, while their geometry on eventual particular supports or adaptors needed for the payloads coupling. The CAD model of such facility has been completed with a proposal for subsystems to be installed on: their components have been selected among the COTS components market.

Final considerations on technological challenges linked to the development of such facility and on its compatibility with the system on which it is expected to operate, have assessed the feasibility of the project: the evolution of the current study may led to the design of a multi-purpose facility able to accommodate payloads and to provide them with essential functions, to be employed in the field of commercial missions.

A structural analysis for the structure optimization and a deeper investigations on already space qualified components are the natural development of the present work.

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