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ESA Space Rider: Payload end to end operations of the European multi-purpose transportation and in orbit servicing system

F. Caramelli*, A. Scaccia*, C. Cossu*, G. Truscelli*, G. Ascanio*, S. Rodriguez*, D. Galli* (ESA); C. Bouthot, J. Salgado**(SCM); S. Carosio***(STAM)**

* *Space Rider Programme, Space Transportation Flight Programmes, Directorate of Space Transportation – European Space Agency, ESRIN Largo Galileo Galilei, 1 I-00044 Frascati (RM), Italy*
** *Space Commerce Matters, 350 North St, Boston, Massachusetts 02113, US*
*** *Executive Director, STAMTech, Via Pareto 8 rosso A – 16129 Genova (GE), Italy*

Abstract

The fast development of "new space" industry has in the last years given birth to new ideas not anymore only addressed to satellite needs but for the development of operations in Low Earth Orbit (LEO) to support R&D and commercial possibilities for pharmaceutical, technological, and manufacturing firms and research institutes. This element, coupled with the extensive background and experience gained thanks to the technical and technological advances of such payload operations conducted with the ISS, now constitute a solid knowledge base to allow LEO become a sustainable marketplace. However, the ISS is only one platform and one that was never intended for commercial operations and manufacturing.

The introduction of Europe's transportation and in orbit servicing Space Rider System (SRS), aims at providing a response to the above instances with a flight cadence that supports scalable manufacturing, which is the primary driver of a commercialised LEO marketplace. SRS is a new platform that offers multi-purpose service mission management, supporting a wide range of payload needs at affordable prices. SRS's flexible model makes LEO much more accessible to the non-traditional space industries, especially those needing return capability.

The SPACE RIDER long-term objective is to define and develop an affordable reusable European space transportation system able to perform experimentation and demonstration of multiple future application missions in low Earth orbit, benefiting to the maximum extent possible from existing launchers technologies, and addressing where relevant progressive technological challenges with limited risks and minimal financial efforts for Europe.
The system shall be able to implement a commercially viable, sustainable and scalable business case; as such, the system shall demonstrate to be commercially self-sustained in the long-term perspective.
According to these mission goals the first Payload Aggregate for Space Rider Maiden Flight is in preparation at ESA with commercial and institutional Customers.

As a central part of ongoing activities devoted to the development of a business model able to express the potential of Space Rider as a new commercial tool, partnership ESA/SCM/STAM has been initiated.

Keywords: ESA, Space Rider, Transportation, Payloads, Service, Reusable, Commercial

Acronyms/Abbreviations

Aggregate Design Authority,	ADA
Assembly, Integration and Testing,	AIT
AVUM Life Extension Kit,	ALEK
AVUM Orbital Module,	AOM
Critical Design Review,	CDR
Contract Research Organization,	CRO
Design of Experiment,	DoE
European Space Agency,	ESA
Intermediate eXperimental Vehicle,	IXV
Guidance, Navigation and Control,	GNC
Health Monitoring System ,	HMS
In-Orbit Demonstration,	IOD
In Orbit Servicing,	IOS
In-Orbit Validation,	IOV
Interface,	I/F
Interface Control Document,	ICD
Interface Requirement Document,	IRD
International Space Station,	ISS
Latching Current Limiter,	LCL
Low Earth Orbit,	LEO
Mass Memory Unit,	MMU
Multi-Purpose Cargo Bay,	MPCB
Mission Timeline,	MTL
Near Infrared,	NIR
On Board Computer,	OBC
Open Innovation Test Beds,	OITBs
Payload Ground Control Centre,	PGCC
Preliminary Design Review,	PDR
Preliminary Mission Analysis,	PMA
Payload Utilization Plan,	PUP
Radio Frequency,	RF
Re-Entry Module,	RM
Research Technology Organization,	RTO
Safety File,	SF
Short Wavelength Infrared,	SWIR
Single Entry Point,	SEP
Space Rider,	SR
Space Rider Ecosystem,	SRE
Space Rider System,	SRS
TeleMetry and TeleCommand,	TMTC
User Payloads Operation Centre,	OPOC
Vehicle Control Centre,	VCC
Vettore Europeo di Generazione Avanzata,	VEGA

1. Introduction

Aim of this paper is to outline the business model in development, describe the end-to-end Service being developed to meet Customer Payload needs and requirements for the various phases of SRS mission, from the vehicle preparation ground operations, the Payload Aggregate definition, selection and integration in the vehicle to the execution of the orbital operations and provide the necessary in-orbit servicing during the two months of flight operations, till the re-entry, landing and post-landing phases, as well as the preparation of the subsequent flights.
SRS is built on the successful ESA IXV (Intermediate eXperimental Vehicle) flown with VEGA launcher on flight number 4 (VV04) in 2015 and in synergy with the VEGA-C launch system.

The primary goal of the IXV project was the implementation of a European re-entry demonstrator capable to maintain and improve the European competencies in the fields of re-entry systems and the related technologies. IXV was launched from Kourou, the European Space Port and described an ascent equatorial trajectory with 5 deg inclination, reaching 400 Km altitude with a suborbital arc and re-entered over the Pacific Ocean where it was recovered successfully.

The heritage of IXV, the consolidated and validated technologies and the acquired experience in the field of re-entry vehicles is maximised in the architecture and the design of Space Rider vehicle; external shape and materials, thermal protections and thermal control systems, part of avionics and GNC algorithms, structural and physical architecture, propulsion system, software concepts, ground control facilities and overall architecture are among the commonalities with the IXV precursor. Space Rider is then complemented by a service module, the so-called AVUM Orbital Module (AOM), derived from the VEGA-C AVUM+ 4th stage upgraded with a life extension Kit (ALEK).

Space Rider major flight mission phases are depicted in Fig. 1a-d and described in detail in the relevant chapter of this paper.

Fig. 1a: Launcher separation

Fig. 1b: Flight Operations

Fig. 1c: Reentry in atmosphere

Fig. 1d: Descent

The Space Rider Project major innovative goals are summarized as follows:

- To develop and qualify the first European reusable system to perform multiple uncrewed missions into space, enabling Europe to gain practical experience on reusability of flight hardware

To commercialise a novel service of in-orbit operations and experimentation, for a variety of commercial and institutional space and non-space applications.

Innovative re-entry technologies and reusability technical challenges are addressed in the design and development of the vehicle, together with design of mission preparation and Payload flight services to meet the two above key objectives.

2. Project Mission

The Project builds on the ESA development, qualification and flight experience of Vega launcher and IXV, enabling users access to and return from low Earth orbits for a wide variety of applications, such as (but without being limited to):

- Micro-gravity experimentation;
- In-orbit Demonstration & Validation of technologies for exploration, orbital infrastructure servicing, Earth and space observation, Earth science, Telecom;
- In-orbit Applications for Earth monitoring, satellites inspection;
- Educational mission;
- European pathfinder for commercial services in access and return from Space.

In terms of supported R&D and manufacturing fields, the applications below are encompassed:

Life Science R&D and manufacturing
- Cell culture
- Molecule crystallisation
- Microorganisms
- 3D bioprinting
- Accelerated disease models
- Medical devices

Physical science R&D and manufacturing
- Deposition
- Formulation
- Furnace crystallization
- 3D printing
- Metal combustion Remote sensing

Remote sensing
- Visible, NIR/SWIR, Thermal IR, Radar, RF

In Orbit Servicing
- Satellite and Payload deployment and retrieval
- In-Orbit assembly and replacement
- Payload In Orbit Services

The reference Space Rider System maximum performance, to be intended as available mass allocated to Payloads inside the Multi Purpose Cargo Bay (MPCB) [1], is of 600 kg, for an allowable volume of 1,2 m^3. This is driven by current Re-Entry Module configuration and by the design at system level with an overall RM mass of 2,950 kg. Performance as given above, is then dependent on the specifics of the envisaged mission:

- the orbit parameters, including the constraints of the geolocation of the landing sites;
- the objectives of the payloads aggregate (observation or experimentation) and the optimized mission profile;
- the performances of the launch system.

3. System architecture

The SR system is composed by a Space Segment, a P/L Aggregate, a Ground Segment and a Landing Site, as represented in Fig. 2.

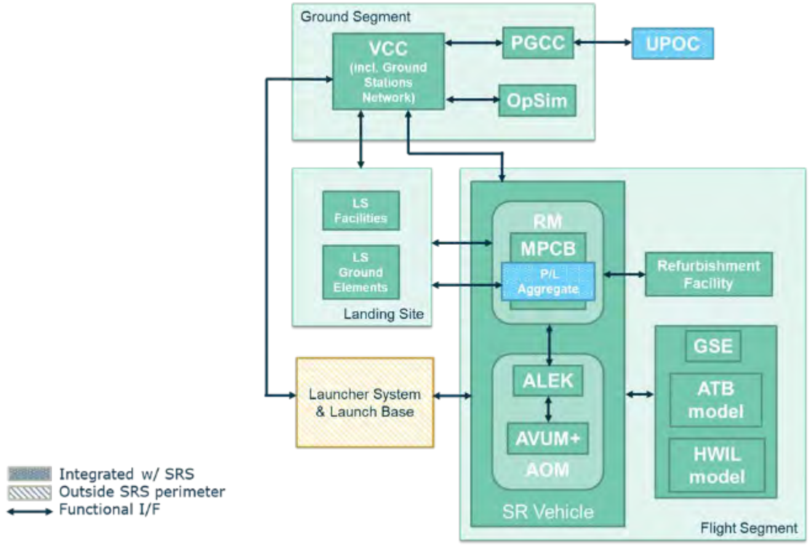

Figure 2: Space Rider System architecture

The **SR Space Segment** is represented in Figure 3, and composed by the following two modules:

- the SR-AOM (AVUM Orbital Module);
- the SR-RM (Re-entry Module), reusable and refurbished after each flight.

Space Rider is launched atop the Vega-C launcher from Europe's Spaceport in Kourou, French Guiana, it will be commissioned and will operate the embarked Payloads during a two months long in-orbit operative phase and it will re-enter on Earth to land in the Landing Site of Kourou, for the recovery of the vehicle and the Payloads.

Figure 3: Space Rider in orbital configuration

The **SR-AOM** is a modified version of the Vega-C upper stage, able to supply power, orbital and attitude control to the whole SR system while in orbit, up to the separation of the two modules prior to return to Earth. It is in turn made of an adapted VEGA-C AVUM+ stage and the ALEK (AVUM Lifetime Extension Kit), a newly developed avionic module whose purpose is to provide electrical power (through dedicate solar arrays, as shown in Figure 4) and thermal control means, as well as data handling and attitude control. After separation and de-orbiting boost, AOM is disposed by means of a destructive atmospheric re-entry. The AOM is represented in Fig. 4.

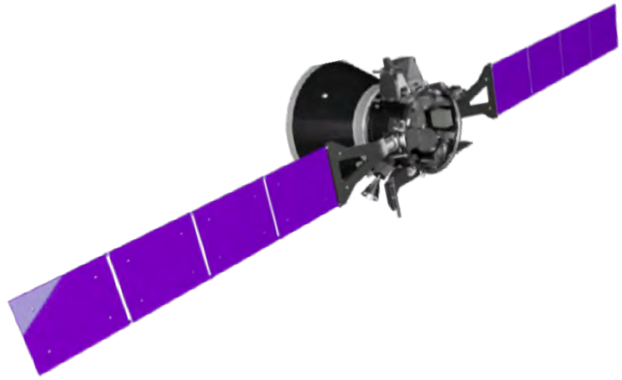

Figure 4: Space Rider AOM

The **SR-RM** is a modified version of the IXV demonstrator, integrating a Multi-Purpose Cargo Bay for payload hosting. The MPCB main door opens during the orbital phase to allow observation and exposure to the space environment, as well as to provide thermal control via a deployable radiator. Furthermore, the vehicle includes lateral compartments, that can be accessed right before launch and after landing, for late access and early retrieval of sensitive payloads, respectively.
At end of its designed in-orbit lifetime (2 months as a minimum), after the de-orbiting boost, the RM is separated from the AOM, performs a guided atmospheric re-entry and lands on ground under parafoil, to allow the Payloads safe retrieval and delivery back to the final Customers. Each Flight Model of the RM is designed to perform 6 flights, upon limited refurbishment. The RM internal view is reported at Fig. 5, in the central area of the vehicle the MPCB is visible.

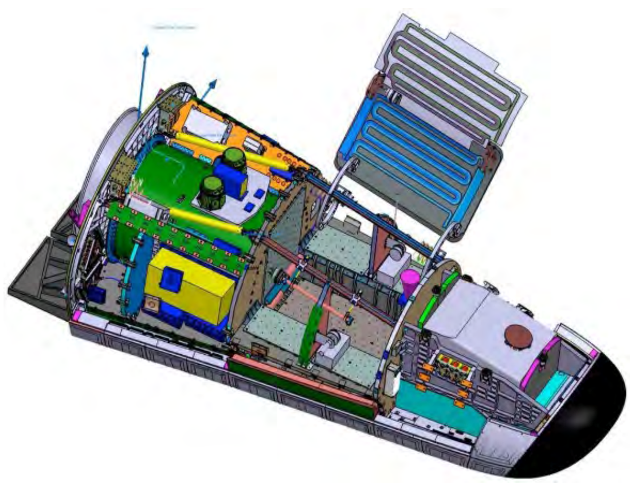

Figure 5: Space Rider RM

The SR stack is designed to be accommodated on the launcher that will enable its orbital insertion; after that event, the SR stack is completely autonomous to perform its designed mission for the planned operative flight time.
The SR stack is therefore performing the core part of its mission as a payload of the chosen launcher system, and it will be as such treated in respect to the process of preparation of the missions.

The Space Rider Ground segment is in charge of vehicle monitor and control from target orbit achievement until early post landing phase when the vehicle is switched off.
The ground segment is composed of :

- VCC: Vehicle Control Centre, in charge to monitor and control the vehicle, and includes the network of stations and the operational simulator

- PGCC: Payload Ground Control Centre which oversees the payload operations and interfaces the experiments centers (UPOCs) on ground.

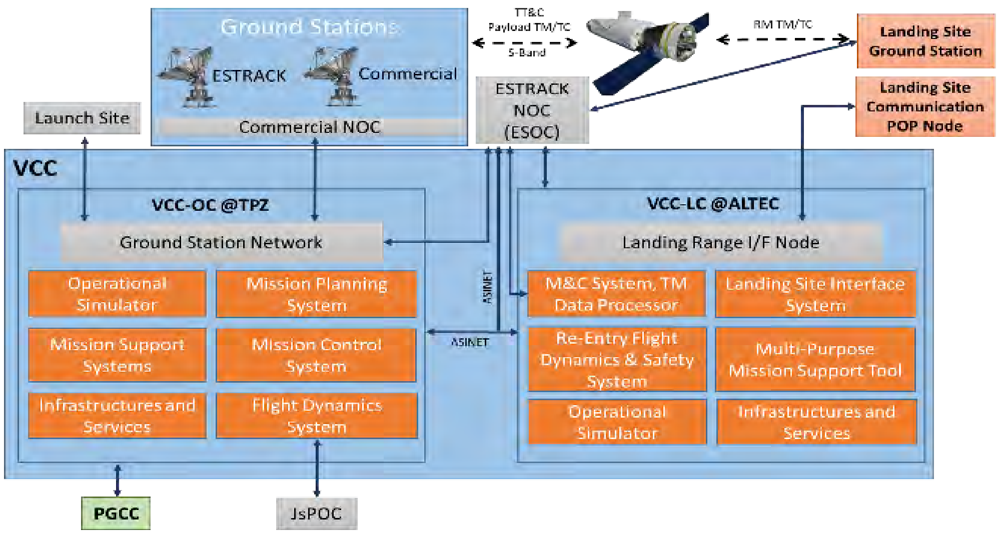

Figure 6: Space Rider Ground Control architecture

Telespazio (TPZ) and ALTEC respectivey in charge of Orbital Centre (OC) and Landing Centre (LC) parts of the VCC.

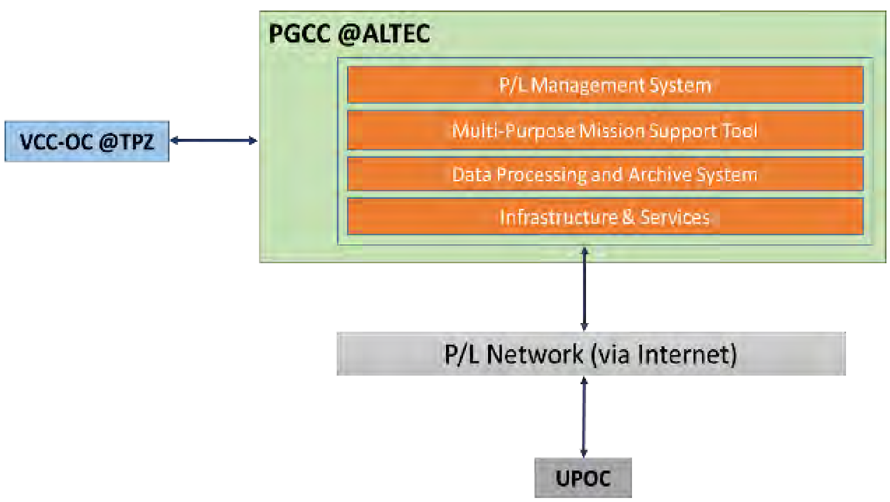

Figure 7: Space Rider Payload control centres network

Fig. 6 and Fig. 7 report all the interfaces and the high-level architecture of the Ground Segment.
All along each Space Rider mission, the Ground Segment will:
- Monitor the S/C and payload activities during all mission phases after achievement of the target orbit, receiving and processing TM data both in real time and through TM dumps.
- Prepare, validate and upload TC products both for S/C and for Payloads as needed.
- Plan and re-plan mission activities including payloads operations.
- Ensure attitude and orbit control as required by system and payloads needs.
- Monitor the AOM during its re-entry phase.
- Monitor the Re-Entry Module during atmospheric re-entry phase as allowed by the duration of the blackout phase and availability of Ground Stations.

- Monitor and command as needed the Re-Entry Module during approach and landing operations.
- Support the Re-Entry Module activities during the post landing phase up to the vehicle switch off.
- Coordinate the activities with the Landing site.
- Archive data (received TM and sent TC) and generate long term archiving products.
- Provide and coordinate specialized engineering support for troubleshooting and performance evaluation.
- Monitor and coordinate the Ground Station Network and the connection with the Remote sites.
- Interface with User Payload Operation Centre

4. Concept of Operations

Building on Vega experience on launch preparation and service implementation, the major phases of a generic Space Rider mission can be synthesized as follows:

1. **Pre- launch phase**: pre-integration and tests, transport to launch site, final integration, and tests, transport to launch pad and integration on launcher, installation of environmental sensitive payloads or sample cartridges during late access operations through the launcher fairing doors and the late access panels of the RM.
2. **Launch and ascent phase**: this phase of the mission is covered by the nominal launch vehicle operations, until the injection of SR into orbit and the commissioning to begin its orbital phase and operations.
3. **Orbital flight phase**: starts with the commissioning and vehicle-level preparations to initiate payload-level activities (i.e., solar array deployment and MPCB door opening); payloads operations following a mission timeline, managed by the Payload Ground Control Centre and the Vehicle Control Centre. This period will last two months or more, with each orbit lasting approximately 90 minutes. This phase ends with the preparations for De-Orbit.
4. **De-orbiting phase:** upon the reconfiguration of the SR for De-Orbit, with activities such as cooling-down (as preparation for descent environment), RM radiator stowage, MPCB door closure and authorization from Landing Site, the vehicle performs the De-Orbit sequence to achieve desired conditions for Re-Entry and execute the De-Orbit boost. This phase then ends with the separation of the RM and the AOM: the RM proceeds to Re-Entry while the AOM performs a destructive re-entry.
5. **Re-entry and Landing phase**: the RM performs autonomously the coasting, Re-entry and Descent sequences. The RM goes from hypersonic to transonic flights till the triggering of a subsonic parachute deployment, slowing down the RM until M=0.2, at an altitude between 6 and 10 Km, followed by the deployment of a guided parafoil for a controlled descent till the landing site, where it reaches ground with proper touchdown conditions and landing accuracy.
6. **Post-Landing phase:** upon landing, the vehicle is monitored, and a remotely guided mobile hangar covers the vehicle prior to operators are allowed to approach and perform the safety activities and early retrieval of payloads. These early retrieval payloads are handed over to the Customer for processing at dedicated Landing Site facilities. The RM is moved to another facility for passivation and decontamination of the thrusters, final payload retrieval and prepared for shipment to the refurbishment facilities.
7. **Post-Flight phase**: a post-flight analysis is performed to identify any non-nominal behaviour and refurbishment needs. The RM undergoes detailed inspections of all subsystems to complete the refurbishment sequence and the maintenance or replacement activities are performed. Upon this, the RM is ready for acceptance for next flight with a new AOM, within six-months.

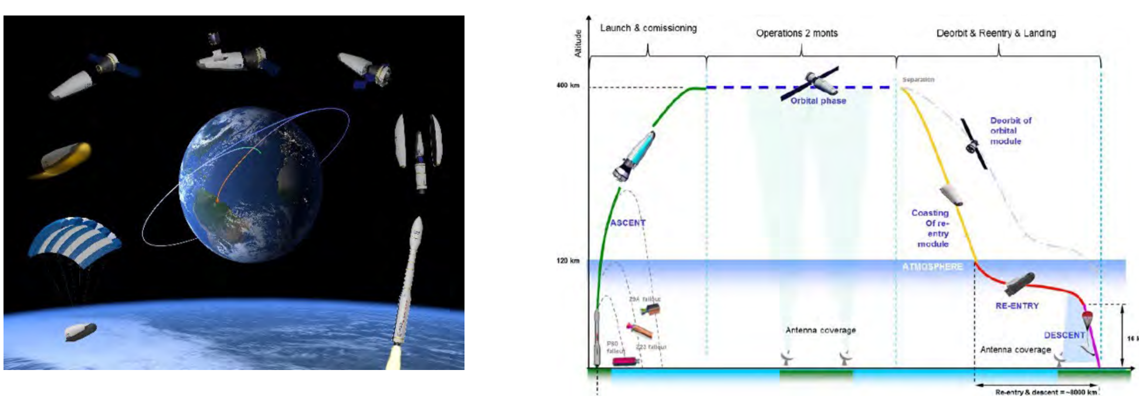

Figure 8: Space Rider generic flight mission

5. Business Models

5.1 Introduction

In parallel to the SRS development and flight mission preparation activities, key topic to encounter the Project Mission goals is the definition of the Exploitation phase; namely the strategic aspects connected with the Industrialisation of the Project within the SRS Flight Model 1 future flights beyond the Inaugural Flight and subsequent SRS Flight Models.

Definition of Industrial Organisation, flight preparation processes, cost balance and revenue models are part of the overall strategy currently in its preparation phase. In particular, special attention is being posed on the investigation of potential Institutional and Commercial market current status and future evolutions; to this end ESA established collaboration initiatives with specialised and experienced entities; in the context of the defined collaboration partnership it has been considered a breakdown for the above mentioned investigations in two major categories, Commercial and Institutional to better focus on the fundamental differences about market approach, Customer management and Payload preparation process characterising them.

5.2 Business Models: Commercial

We are now at a critical stage in the development of space as we see Space Agencies focused on commercializing LEO so that government funding can shift and primarily support the Moon, Mars, and broader exploration goals. Investment into new space platforms is at an all-time high. Private investment in space companies, especially from venture capital, has steadily broken annual records over the past decade. Last year, space infrastructure companies received $14.5 billion of private investment, according to Space Capital.

In 2011, when the ISS National Lab opened its doors for commercial and non-space agency business, there was only the ISS as a platform for fundamental type R&D. Eleven years later, there is a completely new landscape with 4 new commercial space stations and many more new manufacturing platforms and space factories being created to service the non-traditional space marketplace. We are now seeing a space supply-side capability that can service a terrestrial product development need.

Ultimately, we are at an inflection point in space commercialization.

- Access to Space is No Longer the Issue
- It's not just the ISS anymore – many more platforms are coming online
- There is record investment into new space transportation systems and space stations
- The new space factories allow for superior R&D and manufacturing for non-traditional space industry
- These New Developments are allowing LEO to become a new "outsourced environment" which allows terrestrial companies to use their own terrestrial outsourcing models to conduct activity in space
- The time is NOW for Europe to capitalize on this activity with its own space factory: The Space Rider Transportation System

To create a commercial business model, we ensured alignment with current and future market needs. Ultimately, the "build it and they will come" model has proven not to work; consequently, we started with the end-user customer first. We first started with an analysis of the 41 most relevant applications that take advantage of the three unique space phenomena: microgravity, the extreme conditions of space, and the vantage point. We analyzed each of these applications against conditions and constraints (as shown in Fig. 9).

TABLE A	Life Science								
	Cell Culture								
Capability/Constraint Condition	Reg. Med-Organ Trans.	Reg. Med-Micro-organs	Reg. Med-Stem Cells	Stem Cell Bio	Tissue Chips	Accel. Disease-Cell Cult	mAbs-Cell Culture	Vacc. Prod.-Cell Cult	Infectious Diseases
Late Load Requirement	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Operational Time in LEO	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Return Time to Ground after Process	Yellow	Green	Green	Yellow	Blue	Blue	Yellow	Yellow	Yellow
Return Time of Samples after Landing	Yellow	Yellow	Yellow	Yellow	Blue	Blue	Yellow	Yellow	Yellow
Pressurization	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
Volume	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Pre-Process Temperature	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Green
Operating Temperature	Green	Green	Green	Green	Green	Green	Green	Green	Green
Post-Process Temperature	Green	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
High Power Considerations	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Hazard/BSL	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Human Intervention	Orange	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
In-Flight Analysis	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
G-Jitter in Orbit	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
G-Force on Landing	Green	Green	Green	Green	Green	Blue	Blue	Blue	Blue
Compatibility with Other Payloads	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
Terrestrial Lab Requirements	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Figure 9: Example of application vs conditions and constraints

We moved forward with a full analysis of Space Rider capability by mapping the above analysis of feasibility and viability as determined by evaluating each application against the capabilities and constraints of the Space Rider platform (x-axis). We examined *Demand attractiveness* of each application executed in LEO considering the need for return, the initially estimated size and number of markets, existing customer bases, and trajectory to manufacturing, which constituted the (y-axis). And finally, we examined *Flexibility and compatibility* of each application supporting Space Rider's virtual locker concept and ride share versus stand-alone use (size of bubble where larger bubble shows application is more combatable and flexible with other applications) as shown in Fig. 10 below:

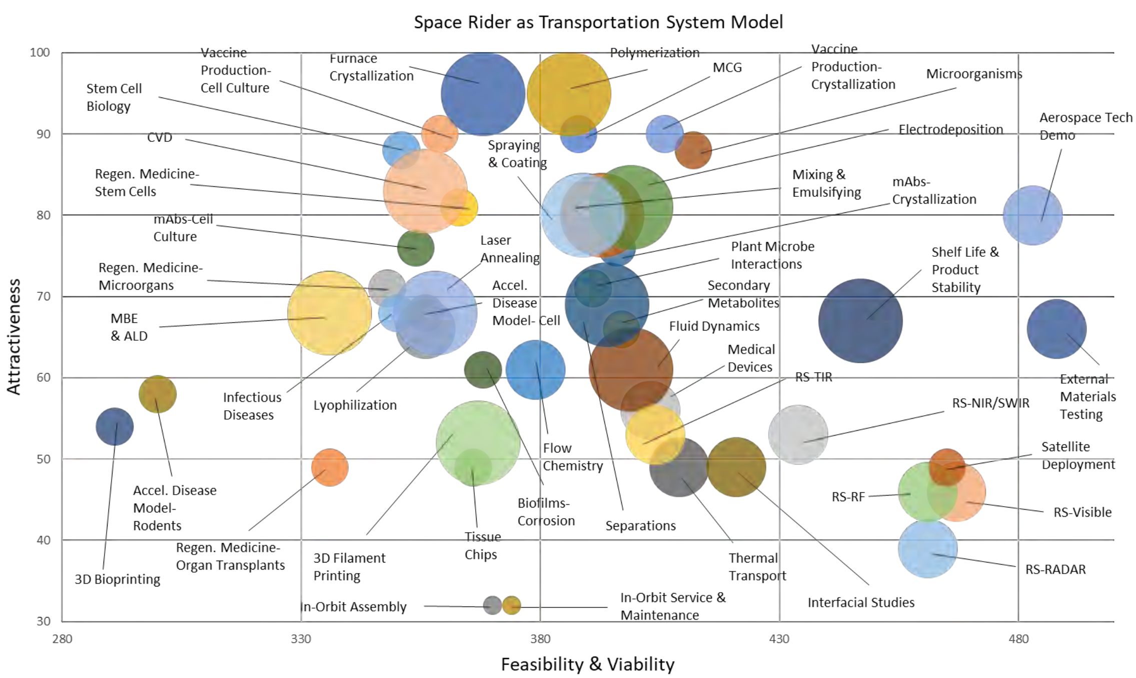

Figure 10: Most attractive applications

Figure Y clearly shows that the most attractive applications are in the upper right quadrant (high feasibility and high market attractiveness with largest bubbles showing application flexibility.

The above analysis allowed us to then progress to the market analysis where we indicated the most promising priority current and future market areas that Space Rider should pursue to attract customers as part of our broader study focused on the creation of a sustainable and scalable commercialization strategy for Space Rider. Here we analyzed 16 major markets, including pharmaceutical, oil & gas, food & beverage, and agriculture to obtain more than 200 unique applications that the Space Rider Transportation System can accommodate.

As part of the market analysis, we identified the following market entry strategies relevant for each application:

- ***Short Term Market Potential:*** Applications with high feasibility, existing capability, and short-term end-user customer revenue potential
- ***Medium Term Market Potential:*** Applications that have near term customer revenue potential but depend upon engineering changes to improve feasibility (e.g., moving the bubbles to the right). These applications are primarily candidates for horizontal integration strategies and partnering with service providers with some level of existing capability
- ***Longer Term Market Potential:*** Applications that have very large markets and commercial potential but also have large gaps with no existing capability and consequently should be considered for vertical strategies and industrial capability development
- ***Opportunistic*:** Applications that are less feasible but still have reasonably large markets. These do not warrant proactive development but instead "piggybacking" on priority applications and taking advantage when possible, from both a horizontal partnership and vertical industrial capability perspective
- ***Passive***: Applications that have the lowest market potential
- ***Not Compatible with Space Rider Model***: Applications that may be feasible however do not have a business model that aligns with a Space Rider Transportation System or those applications that are not feasible. These applications were identified in the application analysis as being not viable for Space Rider and consequently not analyzed in detail in the market analysis.

Shown in Table A is a summary of our market analysis results, which are explained in further detail as follows:

MARKET ENTRY STRATEGIES FOR SPACE RIDER APPLICATIONS				
Stage	Market vs. Feasibility	Strategy	Relevant Applications	
Short Term Market Potential : Currently Feasible, Mostly Existing Capabilities and Defined Customer Targets	Large Markets and High Current Feasibility	Quick Hit Revenue and Horizontal Strategy – use Service Providers with Current Capability and immediately acquire customers	• Shelf Life & Product Stability • Interfacial Studies • Thermal Transport • MCG • External Material Test	• Medical Devices • Microorganisms • Separations • Mixing & Emulsifying • Fluid Dynamics • In Orbit TRL & Test
Medium Term Market Potential - Engineering Modifications: Top Candidates for Moving Bubbles Left to Right	Large Markets but Currently Less Feasible due to Space Rider Configuration	Make Engineering Modifications Moving Bubbles Left to Right and Horizontal Strategy– examine engineering changes that can be made to Space Rider model to make application more feasible for Service Provider Partners to execute	• Spraying & Coating • Polymerization • Electrodeposition	• Vaccine Crystallization • mAbs Crystallization • Flow Chemistry
Longer Term Market Potential - Industrial Capability: Largest Market Potential and Candidates for Vertical Industrial Strategies	Very Large Markets and Large Gaps in Existing Technologies & Capability as well as Low Feasibility	Vertical Integration and Development of Industrial Capability – Consider Industrial Strategies to develop capability to address big unmet needs related to large untapped markets	• Deposition – MBE • Deposition - Laser Annealing	• Deposition – CVD • Regenerative Medicine – Stem Cells
Opportunistic: Piggyback application development above	Large Markets, Less Feasible and compatible with applications in categories above	Piggyback in an Opportunistic way: Take advantage of developments in areas noted above to incorporate these capabilities	• Infectious Diseases • Lyophilization • Furnace Crystallization • Deposition – ALD • Stem Cell Biology	• Accelerated Disease Models – Cell • Organ Transplant • mAbs Cell Culture • Vaccine Cell Culture
Passive: Lowest Market Opportunity	Lowest Market Attractiveness and low feasibility	Passive Customer Acquisition – No proactive customer acquisition strategy: passively support customer interest	• Microorgans • Plant Microbe	• Biofilms/ Corrosion • Tissue Chips
Not Compatible with Space Rider Model– Feasible but Not Attractive Business Models and/or Very Low Feasibility	Currently Feasible Markets but Unattractive Business Models or Not Feasible	Do not Pursue - Not Analyzed in detail	• Satellite Deployment • Service & Maintenance • In Orbit Assembly • Rodent Disease Modeling	• 3D Bioprinting • 3D filament printing • Remote Sensing Operations (RADAR, RF, Visible, NIR, SWIR, Thermal IR)

Table A: Market analysis results

We used the above work to cross reference the 16 markets and more than 40 applications to 200+ unique submarket applications and then identified terrestrial and space-based Total Addressable Market (TAM) estimates by each category resulting in a TAM Value of **780B € over 10 years** for activity that is possible for Space Rider Applications. These TAMs relate to both manufacturing and R&D activity as shown in the example below (Tab. B).

Application	Specific Applications	Top Level Markets	R&D TAM	Mfg. TAM	Total TAM
Deposition - MBE	Building Insulation Materials Nano-Metal Oxides, High Purity Metals High Performance Alloys Optical Sensors	Construction Materials Metals & Mining Aerospace Semiconductors	\$3.77B	\$343.51B	\$347.28B
Deposition – Laser Annealing	Glass Ceramics Heat Treating Crystalline Silicon Photovoltaics	Construction Materials Metals & Mining Semiconductors	\$24.08B	\$110.54B	\$134.63B
Deposition - CVD	Ceramic Matrix Composites Anti-Corrosion Coatings Optical Sensors	Construction Materials Metals & Mining Semiconductors	\$3.75B	\$56.60B	\$60.34B
Deposition - ALD	Electric Capacitors Silicon Germanium Materials	Metals & Mining Semiconductors	\$0.81B	\$3.19B	\$4.00B
Furnace Crystallization	Composite Materials Specialty Alloys Gallium Nitride, Cadmium Telluride	Construction Materials Metals & Mining Semiconductors	\$0.79B	\$2.64B	\$3.43B

Table B: TAM

As a final task, we produced a comprehensive commercialization roadmap detailing potential markets, customer propositions, and customer acquisition strategies to ensure the commercial sustainability and scalability of Space Rider, including the maiden flight pilot customer candidates. To service these customers and execute the strategy, Space Rider has identified a sub-aggregator strategy with service providers that can deliver the necessary capability. Therefore, we also included an analysis of service provider capability with their ability to carry out respective applications and identified what is necessary to integrate with Space Rider as shown in Fig. 11.

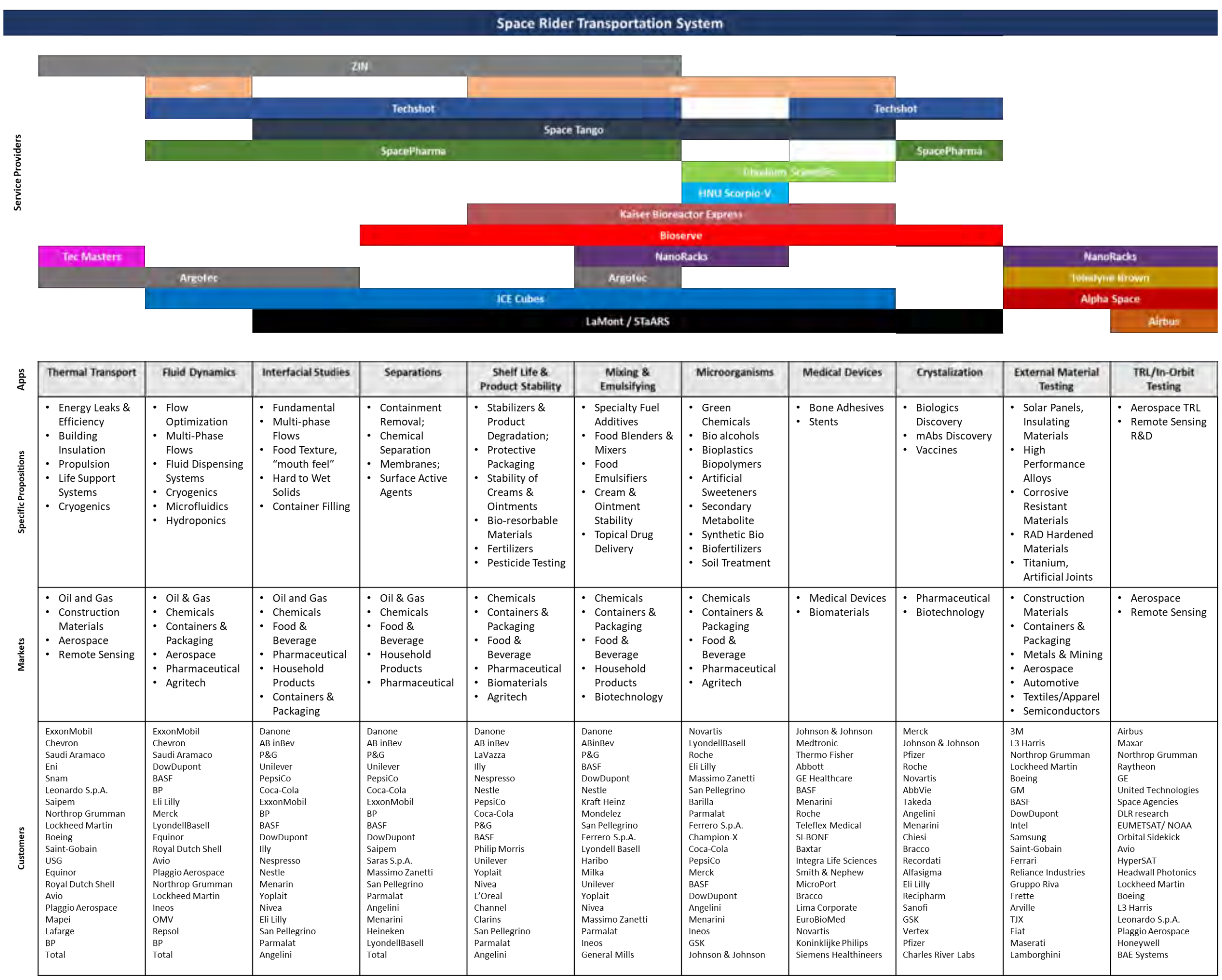

Figure 11: Service Provider Capability

Once we completed our commercialization roadmap, we began an extensive outreach campaign targeting terrestrial-non-space industries identified within the short team revenue opportunity. We created collateral material for Life Sciences, Advanced Material and Manufacturing, and IOD/IOV, that included case studies, explained the importance of space and Space Rider's Maiden Flight opportunity.

A combination of 11 applications and 16 terrestrial markets were identified as short-term opportunities for client acquisition for Maiden Flight and subsequent Space Rider flights. The 11 most promising applications are the following:

- Shelf-Life & Product Stability
- Interfacial Studies
- Thermal Transport
- External Material Testing
- In Orbit Technology & TRL
- Medical Devices
- Microorganisms
- Separations
- MCG
- Fluid Dynamics
- Mixing & Emulsifying

Parallel to that activity we engaged with the Service Providers / Sub-Aggregators to deliver the necessary capabilities as they are one of the key elements on the execution of the commercialization strategy. Therefore, we performed an analysis of service provider capability to carry out respective applications and identified what is necessary to integrate with Space Rider.

As we move forward, we will continue to align the Space Rider System with business and pricing models that replicate terrestrial models – especially those in the outsourced R&D and manufacturing areas. The movement from a traditional space revenue model to a non-traditional space model will allow scalability and ultimately, larger revenue numbers.

5.3 Business Models: European Institutional

The collaborative research landscape in Europe

Based on the work on the commercial business model for Space Rider, STAM has investigated its declination from an institutional point of view investigating the potential to create a proactive ecosystem made of large, small and start-up companies, with a focus on the Life Sciences and biotech sectors. The goal is to design a model to generate a critical mass of potential ventures as deal flow to select high potential business cases which could benefit from acceleration towards in-space manufacturing and experimentation.

We started from a critical analysis of the key Space Rider's features and differentiators, namely: the volume of payloads, the unmanned condition, the extreme environment. While Design of Experiment (DoE) on Earth is well known to Life Science innovators and scientists, bringing experiments on-orbit is a completely unexplored area for them. Even when the positive outcome could be greater from the scientific point of view, and profitable, the barriers to space can hinder the interest of future customers.

In recent years, Europe has been increasing its level of expenditure on research and development to help the generation of innovations in this sector. In 2020 the pharmaceutical industry invested more than €39,600 million in R&D, representing the industry sector where R&D activity is greater as a percentage of net sales. R&D costs per new medicine (accounting for the cost of failures) ranged from US$944m to US$2,826m, where clinical development accounts for 50-58% of R&D costs per new medicine [2]. Horizon Europe and associated European support initiatives are the largest budget at world-wide level, amounting for health-related research to over €8 billion in the period 2021-27.

It is known that several research activities in the Life Science sector are carried out by small enterprises, mainly innovative startups and university's spin-offs which develop breakthrough solutions with external funding, looking at attracting companies with the firepower to go through the validation path and commercialize their innovations. Furthermore, the collaborative interaction between companies and external knowledge-based parties (RTOs, CROs and Universities) makes available advanced research infrastructures and validation facilities.

A Single Entry Point for in-orbit research and manufacturing

Space Rider has the potential to enable a new paradigm to access micro-gravity research and in-space manufacturing which leverages on the creation of a wide ecosystem to create a sustainable deal flow. Space rider can become a broad and complex scientific facility, with a lot of opportunities for the Life Science sector.

This is in-line with the experience developed within the framework of the Open Innovation Test Beds (OITBs) initiative by the European Commission, which fosters community of users, large and small enterprises with a key role for start-ups. They are organized to allow an easy and sustainable access by industry to several research facilities from all over Europe. The final aim is to support the customers along the innovation journey to the market for their innovations.

The complexity of the entire OITB organization is connected to the number of actors to involve which require aggregation at different levels. If we translate this model within the framework of Space Rider, we need to move beyond the DoE. The mission to space requires additional expertise in space technology, automation, energy management, data collection, to name a few. OITBs answer this need through the proactive work of a Single-Entry Point (SEP), which is the customer-attracting entity and an orchestrator of marketing efforts. The SEP is responsible for collecting and evaluating the business opportunities through a funnel-based approach and key accounting support towards customers/prospects.

The SEP will facilitate aggregation of expertise and service providers to support the implementation of the experiments and their integration as payloads in the specific flight window. The model design is also looking at the experience and lessons learnt from Arianespace and the associated value proposition and operational model.

Space Rider Ecosystem

The SEP will be the contact point for the clients. However, finding clients will not be an easy task. Given the complex framework in which Space Rider operates, it is necessary to create an engagement plan able to attract multinational companies, SMEs, start-ups and research centers, presenting the opportunities and the advantages of in-orbit experimentation and manufacturing.

This task will require a great number of possible customers to funnel the research interests and increase the probability to find a paying customer. The proposal is to create and animate a dedicated Space Rider Ecosystem (SRE). This will be the place to share best practices, find new partners for collaborative research and increase the opportunities to expand the research outside the boundaries of the proprietary laboratories. The SRE will benefit from several dedicated services, such as: project management; activities to engage stakeholders; funding opportunities; IPR services; access to specialistic information and selected data generated from the missions.

The business case with orphan drugs

The work on the business model from an institutional point of view, valuing the public and private dimension of the ventures behind the experiments to be launched, is still ongoing.

A dedicated workshop with industry and key stakeholders highlighted the market segment of rare diseases and orphan drugs, with a focus on the ophthalmic sector as an area with high potential versus the Space Rider features. Small batches allowed by the payload are in line with the orphan drugs market, while the subsidies available to source and supply these drugs could allow to sustain the higher costs related to the in-space development. This is accompanied by specific actions at European level which may support the experimental stages and in particular the access to Space Rider as unique research facilities.

6. Design to Service

In this section highlights about design aspects of the system are reported, theyc are believed to positively impact on overall capability to encounter Payload needs and requirements, to position the Project in a commercially promising market area.

- The vehicle design is based on existing and flight proven hardware; the RM is derived from the successfully flown IXV. In particular, the critical external shape and hot structure including external thermal protection system are identical to the precursor, the cold structure is strictly derived from the precursor and reinforced to sustain both the novel cargo bay area and the increased mission requirements connected to the orbital and reentry phases.
- The system is designed according to unmanned safety standards; this implies remarkable simplifications if compared to other servicing platforms.
- Vehicle dimensions, limited vehicle-produced disturbances and routine in-flight vehicle operations allow for long high quality micro-g standard (1E-6 g) periods at defined conditions, compared to other platforms.
- Together with return capability, after landing operations and GSE design allow fast recovery of experiment sample

results on the airfield and return of Payload hardware to owners.
- Dedicated flight service organization, optimizing involvement of selected service providers, allow minimal effort by experiment owners on interface management with the vehicle
- Unlike other platforms, Space Rider is conceived not only for experimentation but also for in- space manufacturing, that will allow to pave the way for opening of new markets to in-space operations
- The system reusability roadmap is structured in such a way that flights will be possible at 2/Y rate, with corresponding mission preparation fast pace
- Flight and Ground segments communication network is structured to allow maximum User data privacy on data, operations, industry knowledge protection.

7. Focus on the Cargo Bay

The vehicle cargo bay: Multi Purpose Cargo Bay (MPCB) is conceived to allow maximum standardization of Payloads accommodation effort and preparation of services.

The vehicle MPCB is accessible from the upper RM door, used for Payloads AIT activities on ground and opened during Flight Operational phases.

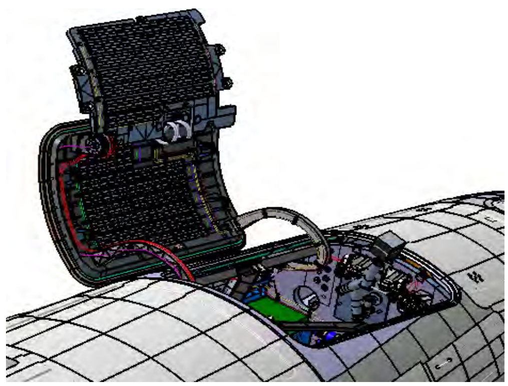

Figure 12: RM MPCB upper door

Two additional lateral openings are available in the RM, dedicated to AIT of special Payloads requiring Late Access operations; this is made possible until 24 hours before Lift Off by two lateral doors dedicated to this function and sealed during flight phases. To enable Payload loading operations at such short time before lift off, the launcher fairing is provided with dedicated fairing windows.
The two RM lateral doors will then be available to allow access to Payload after landing for early retrieval.

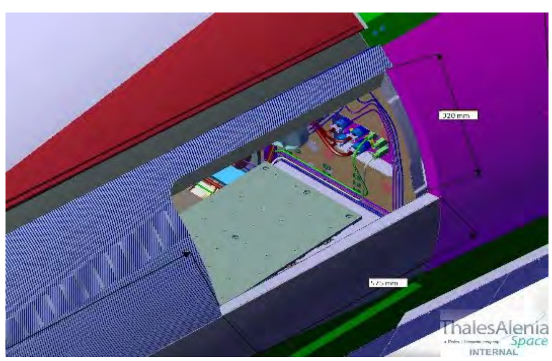

Figure 13: RM MPCB Lateral Late Access door

The MPCB mechanical interfaces with Payloads are standardized by means of vehicle MPCB Support Plates whose positioning covers the available sides of the bay. The thermal control of all Payloads will be guaranteed by a Thermal Control System (TCS) by conductive heat exchange through the MPCB Support plates, power and data lines interface points allocated in the MPCB to guarantee adequate servicing to all Payloads in the Aggregate. In Fig. 14 the Support Plates depicted in orange are shown.

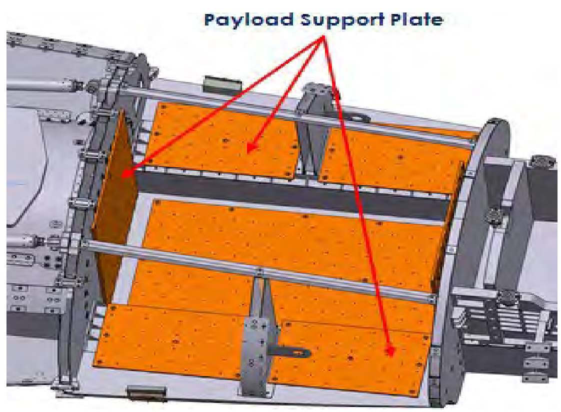

Figure 14: MPCB Payload support plates

The MPCB opening door is designed to allow 90 deg Field of View to Payloads dedicated to observation missions, deployment or external operations. In Fig. 15 a font view of the RM allows to appreciate the FoV angle.

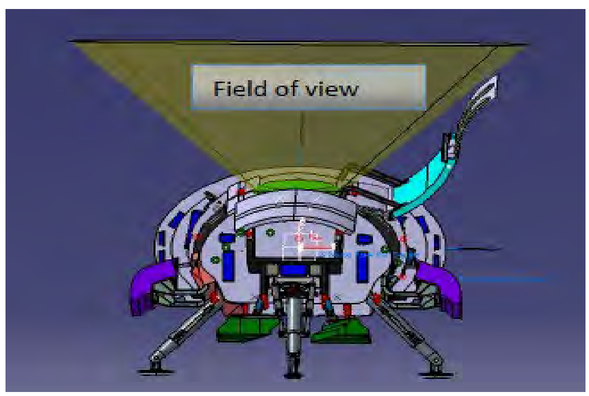

Figure 15 MPCB upper 90 deg cone angle FoV

Space Rider architecture and the available MPCB services allow In Orbit Servicing (IOS) capabilities to the RM either in stand alone or collaborative system configurations. In Fig. 16 a sample IOS operational configuration, featuring a robotic arm onboard for handling objects and/or supporting interaction with external bodies is shown.

Figure 16 Space Rider IOS concept in study

8. Payload preparation and Aggregate design

The SRS payloads preparation and aggregate design follows an end-to-end structured process to guarantee for each flight mission the aggregate coherence and compatibility with SR system and safety requirements.

The process is subdivided in different phases (0-6) to cover the Payloads Aggregate major preparation activities, from payload selection to retrieval post-flight. An open system loop approach is followed in the initial phases until aggregate finalization to allow for flexibility of payload accommodation according to each customer programmatic and technical readiness. Payloads own development and qualification activities are performed in parallel to this process by the payload owner.

Phase 0 involves preliminary screening and assessment of potential payload candidates' proposals mainly based on compatibility of payload declared interfaces with SR capabilities and mission characteristics. Suitable selected payloads are then invited to submit more detailed information in the form of predefined Interface Requirement Document and Safety File to advance to next phase.

Phase 1 regards the preliminary accommodation studies in the MPCB based on the information provided by payloads in IRD and SF. Payloads accommodation in this phase mainly considers mechanical, thermal, power and TMTC constraints. Different aggregate configurations are elaborated for optimization of Customer needs and vehicle service capability. Regular I/F meetings with payload customers guarantee the availability of updated information at each stage of the payload own design and development process.

Phase 2 introduces the contribution of the SRS Industry Prime (as Aggregate Design Authority) to first assess the feasibility of the preliminary configurations studied and then to perform based on payloads consolidated data (i.e., at least at PDR level allowing the signature of a MoU with the payload customer) the Preliminary Mission Analysis. The objective is to evaluate and confirm a suitable preliminary Payloads Aggregate that is harmonized and compatible with the vehicle capabilities and mission timeline. A first version of a Payload Interface Control Document (ICD) is issued towards each payload customer to define and control the applicable interfaces.

Phase 3 deals with the execution of the Final Mission Analysis by the ADA based on CDR level payload data (allowing the signature of a FSA with the payload customer) to confirm the final Payloads Aggregate design. This phase includes the missionization of the vehicle to the needs of the defined Payloads Aggregate with MPCB hardware adaptations where needed, system software and procedures missioning, ground and flight operations plans definition. Final version of payload ICD is signed with the customer.

Phase 4 foresees the execution by the SRS Industry Prime of the AIT activities to allow the integration and verification of the Payloads Aggregate into the vehicle. AIT operations of e.g., bio cartridges of Late Access payloads will be performed at the launch pad according to the launch preparation timeline.

Phase 5 regards the inflight operations of the Payloads Aggregate according to the predefined mission timeline. The PGCC (directly interfacing with the VCC and the UPOCs) is dedicated to Payloads monitoring and telecommand during this phase.

Phase 6 deals with post landing operations with payloads disembark and handover to customers, including early retrieval at landing site of e.g., bio cartridges if required by Payloads.

A standardised Payload Aggregate preparation process has been conceived to optimize efforts and allow reasonable lead time Customers follow up and mission preparation, coherent with Project target launch rate of 2 flights per year. The design of the SRS First Mission is currently in implementation phase; alternative Payload Aggregates are in a preliminary design phase, according to Customer portfolio achieved to date, in Fig. 17 some examples of MPCB arrangement in study are reported.

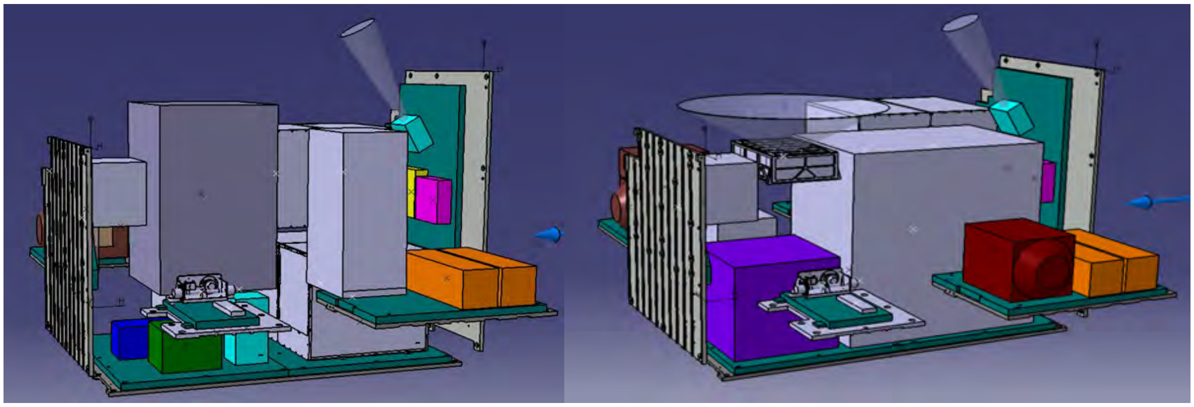

Fig. 17: sample MPCB Aggregate design, Payloads accommodation

9. Service Governance

Flight preparation and implementation service to Payload will adopt Service Provider entities with expert knowledge on Payload Customer management from technical, programmatic and commercial stand points.
This approach will be in favour of standardization of the Payload preparation processes and simplify the effort from vehicle system of the complex definition and management of the Payload Aggregate.
The design of the Aggregate is at the system level in charge of SRS Industry Primes, to guarantee compliance with vehicle capabilities and meeting of harmonized requirements of all Payloads in the Aggregate.
Th First Mission of SRS will see ESA leading the MPCB Aggregate preparation process and is missionization and management until post landing phase; however already at early stages of the process Industry Primes and Partners are actively involved in view of future evolution of the Aggregate missions management towards Project commercialisation.
The scheme at Fig. 18 reports the hierarchical organization defined together with a non exhaustive list of major tasks ateach hierarchical level for the preparation of SRS MPCB Aggregate flight.

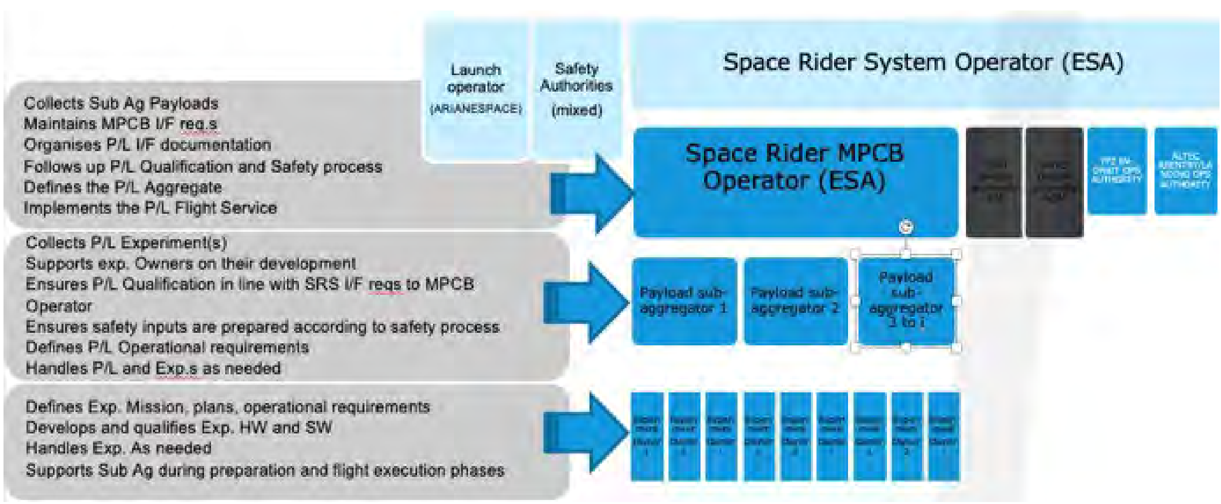

Figure 18 Payload service governance

10. Services to Customers

SRS design is conceived to offer on-board standard services to Customer Payloads, listed as follows:

Late access and early retrieval
Late access for sample cartridges installation up to 20 ours before launch

Early retrieval of sample cartridges possible starting from 3 hours after landing

Micro-g

10e-6 g max.

Deep space observation and Earth Monitoring

From the MPCB opening window, a 90deg Field of View is possible and deep space observation or Earth monitoring are possible, according to attitude.

Power

SR makes available 11 LCL 28 V unregulated power lines, rated between 10 and 400 W. Of the power generated by the solar arrays, the vehicle can feed up to 600 W to the P/L aggregate.

Temperature control

While on-orbit, the MPCB plates and the thermal control system of the RM allow the dissipation of 600 W for the Aggregate of payloads. This allows to set the Payload I/F temperature in the range 15-40C.

TM/TC

SR offer the possibility of storing payload housekeeping and scientific data (3.6 GB/day) on the vehicle MMU and downlink (2 GB/day) via the arranged ground station network, and shared among the Aggregate. Furthermore, there is also the possibility to uplink telecommands. The mission timeline and visibility windows for communications are managed by the PGCC and VCC.

Accommodation

The MPCB can accommodate a total of 600 kg of payloads, along with their mounting devices and harness.

Special services for Payloads specific need are defined on a case by case basis; in an evolutionary approach, they will be considered for continuous upgrade of SRS capabilities towards Customer needs. To date, Payload separation from the vehicle and Payload pressurization are among those in preparation, while the former is currently available, the latter is in a design phase through the definition and development of dedicated MPCB modules.

11. Ground services and operations

Space Rider operations start on-ground with the manufacturing, assembly and integration of both the RM and AOM modules, which are then transported to Kourou for final integration and checks, in preparation for launch.

The payloads can be installed in Europe, along with the assembly, integration and testing activities of the RM, or be shipped directly to Kourou to be integrated in the RM during launch campaign.

For the preparation of the payloads and of any sample cartridge to be inserted during late access operations at the launch pad or post-processing upon retrieval, at Launch Site and Landing Site SR can provide as a service certain Payload preparation laboratories of bio class level together with facilities and equipment.

In anticipation to launch the payload preparation complex will directly support the final integration of SR.

After landing, the early activities will be performed under a mobile hangar, directly at the landing area to allow earliest possible bio-Payloads retrieval from the landed RM. Then the RM will be moved to a vehicle facility for post-flight activities and retrieval of the remaining payloads. At this point in time, the Customers can make use of the dedicated Payload Processing Facility, as well as the available equipped offices.

12. Flight operations

Because of to the high flexibility of the vehicle the Ground segment and the operations are conceived to be as flexible as possible to serve the different missions objectives and reduce the ground operations.

During Routine Orbital Phase, the Mission Timeline (MTL) loaded in the RM and AOM OBC will drive the execution of the activities and their epoch: actions identified in the various entries of the timeline will be autonomously performed by the Space Rider System, unless off nominal situations will occur.

In coordination with mission Payloads Aggregate preparation and according to the designed flight operations timeline requests of all the Payload Customers composing the mission Aggregate, the Payload Utilization Plan (PUP) will be the key baseline standard to generate the MTL and the connected flight procedures to enable monitoring, control, telecommand, together with the telemetry downloading.

The Ground Segment system architecture allows to update during operations the Payloads timeline and related needs to account for specific up-to-date requirements from Customers; as such, the relevant MTL updates will be uploaded as nominal process from ground.

13. System and project status and planning

The Space Rider Project went through its System Critical Design Review in June 2022 and is currently implementing all the agreed actions and recommendations in order to close the phase C within Q1 2023. The qualification phase D will then span throughout 2023 and 2024 encompassing, among the others, several RM drop tests (by means of either small scaled, full scaled or fully RM representative test vehicles), multiple avionic test benches and a full environmental qualification based on a proto-qualification approach; the inaugural Flight (First Flight) is currently targeting end of 2024.
Among the most challenging aspects of the system design, the precision landing under parafoil and the demonstration of RM reusability will be European novelties, requiring substantial development and use of cutting edge technologies. Parafoil landing implies development of several different technologies and their harmonisation for final successful operations, foil design, guidance and control algorithms, landing mechanisms to minimise the landing loads on Payloads and sustain the shock are among them.
Reusability of the RM for at least 6 subsequent missions is also challenging the design of vehicle components, definition of Health Monitoring System (HMS) and optimisation of the refurbishment phase both from technical and programmatic stand points.

14. Conclusions

This paper provides an overview to the ESA SPACE RIDER SYSTEM and the Project scope, introducing essential elements to describe the business development approach being followed along with key information on the offered services to Payload Customers, in an effort dedicated to develop not only the necessary technical capabilities to implement the defined Project missions but also to prepare a commercially viable solution for use by European Industry of the opportunities offered by the Space Rider transport and orbital platform.

15. Acknowledgments

The authors acknowledge the key role played by the whole ESA and Industry Space Rider team and Partners in the effort to continuously enhance and improve the Space Rider Project servicing capabilities and proactively contribute to the new challenges posed by the development of Project business model for the future success of this initiative.

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