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Space Rider – The Operation Concept for the First and Ambitious European Affordable Reusable Space Transportation System

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Abstract

The Space Rider program is an innovative mission that opens new perspectives for affordable and reusable space transportation system. It is designed to embark different kind of payloads with the objective to perform experimentation and demonstration of several future mission application in Low Earth Orbit. Considering the variety of payloads and their operability, the execution of the orbital operations is based on a complex and detailed planning, assessed and prepared prior to the launch and updated during the flight.

The system will exploit to the maximum extent existing technologies to be affordable to sustain several commercial mission flights using the same re-entry module. It is also designed to allow execution of autonomous operations to the maximum extent. In particular, it will make use of innovative re-entry technologies for reusable systems. The system will allow a controlled re-entry ending with a very precise and safe landing, ensuring experiments return from the orbit back to the Earth.

Although the on-board GNC system will perform autonomously the re-entry and landing, an essential support from the ground is required in terms of re-entry planning, monitoring and uplink of the necessary wind parameters information.

Many processes and procedures are currently under development, in order to ensure the successful landing on a very precise area. Several contingency and abort scenarios are identified, and consequently associated procedures will guide the resolution of any issues, in order to ensure the safety of the mission.

Besides the above-mentioned targets, main mission operations drivers and constraints are also identified in the mission profile, in the ground stations network, in the data downlink needs, and in the maximum reuse of the system and its operations concept for the different flights.

The objective of this paper is the description of the developed new operational concept, for the various phases of the mission, from the execution of the orbital operations till the re-entry, landing and post-landing operations, as well as the preparation of the subsequent flight.

Keywords: Mission timeline, payloads, de-orbit, re-entry and landing, nominal and contingency operations

Main Acronyms/Abbreviations

AOM: AVUM Orbital Module
AVUM: Attitude Vernier Upper Module
FOD: Flight Operations Director
GS: Ground Segment
LEOP: Launch and Early Operations Phase
MPCB: Multi-Purpose Cargo Bay
MTL: Mission TimeLine
PF: Platform
PGCC: Payload Ground Control Centre
PL: Payload
PLMS: PL Management System
RM: Re-entry Module
ROD: Re-entry Operations Director
SR/SRS: Space Rider / Space Rider System
VCC-LC: Vehicle Control Centre – Landing Control

VCC-OC: Vehicle Control Centre – Orbital Control
UPOC: User Payload Operation Centre

1. Introduction

Space Rider is a fully European project, led by the European Space Agency (ESA), in collaboration with AVIO and Thales Alenia Space Italy (TASI) as prime contractors for the flight segment, and ALTEC and Telespazio as prime contractors for the Ground Segment and operations. The project consists in the design and development of a first reusable European space transportation system to be launched by the VEGA-C launcher and able to perform experimentation and demonstration of multiple future application missions in low Earth orbit [2].

The program foresees to have a first demonstrative flight (maiden flight) and five more commercial flights reusing the same re-entry module.

The maiden flight launch is foreseen from the Europe's spaceport in Kourou, French Guiana. Each mission flight will consist in two months of in-orbit operations and a subsequent de-orbiting, re-entry and landing.

Depending on the chosen orbit inclination for each flight, different landing sites are considered. All of them will be equipped with various systems which will support the re-entry module descent and landing, including the safety function. For the maiden flight an equatorial orbit with 6.2 degrees inclination at about 400 km altitude has been chosen and the Europe's spaceport in Kourou (CSG) has been selected as landing site for equatorial orbits.

Space Rider is conceived as a multi-type mission, for a wide variety of applications such as: micro-gravity experimentation, radiation exposure; in-orbit demonstration & validation of technologies for exploration, orbital infrastructure servicing, Earth and Space observation, Earth science, telecommunication; in-orbit applications for Earth monitoring, satellites inspections; educational missions; European pathfinder for commercial services in access and return from Space.

The Space Rider mission is a successor to the ESA's pioneering Intermediate eXperimental Vehicle (IXV) mission. It was an experimental sub-orbital re-entry vehicle for testing in flight technologies. IXV was injected into a suborbital path attaining an altitude of around 412 km, ans re-entering immediately after the atmosphere at an altitude of 120 km – fully representative of any return mission from low orbit.

The heritage of the IXV mission is particularly important for the design of the Space Rider system and of the operations of the re-entry [1]. The vehicle is in fact an advanced version of the IXV, which allows not only the re-entry, but also a precise landing, thanks to a dedicated on-board guidance system. The overall operations, in terms of ground visibilities, procedures and criticalities resolutions also benefit from the experience gained.

The Space Rider System is composed by the Flight Segment and the Ground Segment described in the following.

1.1 Flight Segment

The Space Rider Flight Segment is composed by the following two main systems:

- SR-AOM (Space Rider AVUM Orbital Module): composed by the Attitude Vernier Upper Module (AVUM), and the AVUM Life Extension Kit (ALEK) to perform all the actuation manoeuvres required during the orbital phase.
- SR-RM (Space Rider Re-Entry Module) is based on the IXV demonstrator modified as necessary to implement all the changes induced by the Space Rider mission needs. This module embarks the payload within its Multi-Purpose Cargo Bay (MPCB) and ensures the re-entry up to the precise landing and re-flight.

The AOM performs mainly the power supply from the solar panels, with the AOM battery recharging, and the guidance and navigation control during the in orbit phase. Its GNC in fact, is responsible for the manoeuvres during the orbital phase, for the de-orbit activation, the AOM-RM separation, and finally for the AOM destructive re-entry. It also performs the attitude changes, dictated by the mission needs and the pointing for the payloads experimentation. The AOM computer communicates directly with the RM one for the management of all the activities and the communication with ground. In fact, the communication with ground during the orbital phase is established from the RM.

The RM is the reusable part of the Space Rider System providing the accommodation of the payloads within its MPCB and the associated services. It has the direct communication link with the ground stations for data downlink and command uplink. It has the capability to govern the atmospheric re-entry through the combined action of the propulsion thrusters and of the aerodynamic flaps, slowing down from subsonic regime through the guided phase under parafoil. On board the RM, a dedicated GNC guides the descent phase under parafoil and allow a landing with a precision of about 150 m.

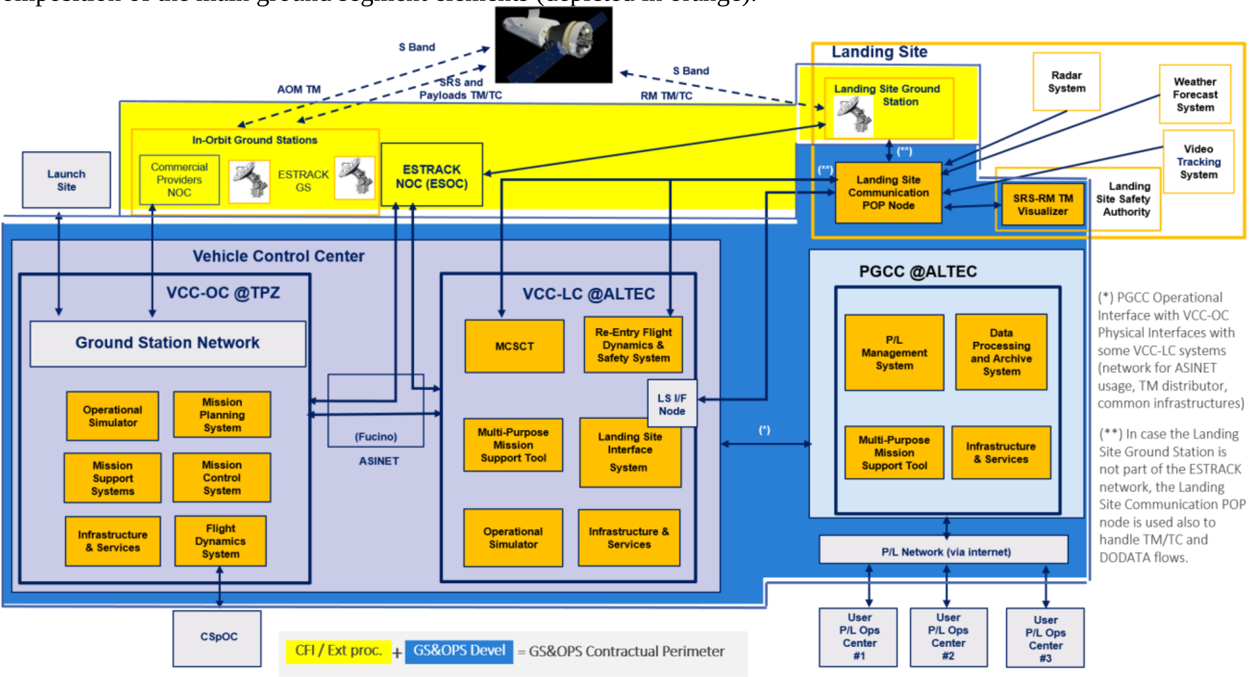
Being the reusable part, it is refurbished during the on-ground period before the subsequent flight (approximately six months).

1.2 Ground Segment

The Space Rider Ground Segment is made by the following major elements:

- The Mission Control Centre (MCC), which is composed by two main entities:
  - VCC – Vehicle Control Centre, that is in charge of the vehicle monitoring and commandability in all the phases of the mission and is responsible for both in-orbit and re-entry and landing operations. It is based on the use of the customized SCOS system for the platform control, while payload data are managed by a microservices-based telemetry management system (TM DDS). In particular, VCC is distributed in:
    - VCC-OC: physically located in Fucino and responsible for all the in-orbit operations and activities.
    - VCC-LC: physically located in Turin and responsible for the re-entry and landing operations (hosting also the Engineering Support Room).
  - PGCC – PL Ground Control Centre, physically located in Turin that is the centre responsible for the payload operations and ensures the interface/co-ordination with the User Payload Operations Centres (UPOCs)
- The Ground Station Network (GSN), that is logically managed and allocated in the VCC. It includes all the ground stations which support the Space Rider mission.
- The Operational Simulator (OPSIM), used to support system and subsystem level verification, as well as to perform simulation campaigns, and support mission operation for training and simulation activities.

The whole Ground Segment with its interfaces with the external entities is shown graphically in Figure 1 with a decomposition of the main ground segment elements (depicted in orange).



(*) PGCC Operational Interface with VCC-OC Physical Interfaces with some VCC-LC systems (network for ASINET usage, TM distributor, common infrastructures)

(**) In case the Landing Site Ground Station is not part of the ESTRACK network, the Landing Site Communication POP node is used also to handle TM/TC and DODATA flows.

Figure 1 Ground Segment Overview

Some of the tools will be used in common by the different centres.

Within the VCC, some tools are used in both VCC-OC and VCC-LC:

- OPSIM: deployed in both VCC-OC and VCC-LC, to support both system/subsystem verification and operational activities
- TM DDS: deployed in both VCC-OC and VCC-LC, to allow the HK TM monitoring from external users and, at re-entry, from safety functions. In particular, it also performs the payload data archiving and dissemination allowing the proper management from PGCC.

- Mission Control System and Common Tools (MCSCT): deployed at the VCC-LC in order to align the VCC-LC site with SRS commanding, events and telemetry data.

Within the PGCC, instead, the main system in charge of managing all the PLs operations is the PL Management System (PLMS), which services are used both by the PL end-user at the UPOCs and by the PL operators at the PGCC, although with different privileges, to provide inputs, plan the PL operations, and monitor the execution of the experiments

A system of voice loop is used to communicate both with internal (within VCC, PGCC) and external (Landing Site) entities.

In addition, a room is dedicated to the Engineering Support Team, which is composed by flight segment experts and provide support along the whole mission especially in case of SR anomalies.

This paper is focused on the orbital phase and on the de-orbit, re-entry and landing phases. It describes first which are the requirements and the constraints which drive the development of the mission and then it describes the developed operational concept for flight operations.

2. Mission Operations Requirements

The objective of the ground segment operations is the execution of the LEOP & commissioning, routine, preparation for de-orbit, de-orbit, re-entry, landing and post landing activities up to vehicle switch off, bringing the Space Rider vehicle from the target orbit achievement to its RM safe landing. The Ground Segment operations have to be executed for up to six recurrent missions (including the maiden flight), also accommodating different payloads. The launch of the subsequent flight is foreseen within approximately six months after the completion of the previous mission.

The Space Rider operations are driven by the following main requirements:

- Launcher: the spacecraft is injected in orbit by VEGA-C launcher.
- Safety: the trajectory shall be constraint such to ensure a safe re-entry flight both in nominal condition and for an anticipated re-entry. It has also to consider the safe AOM destructive re-entry. Also, operations need to be monitored for object collision avoidance.
- LEOP and commissioning duration: the target nominal duration shall be kept as short as possible, in order to allow immediate execution of biological experiments.
- Ground visibility: activities identified as "critical" shall be under direct ground visibility (i.e., with real-time monitoring) with particular focus on:
  - Target orbit achievement and Sun pointing mode transition;
  - De-orbit operations: the deorbiting starts from the moment in which the command, which allow to start the preparation for de-orbit on-board, is uplinked and it finish at the AOM-RM separation. After the separation, the AOM lowers the perigee to target a controlled destructive re-entry. The de-orbit, separation and AOM destructive re-entry operations shall be performed under visibility. The following conditions are necessary for the handover from the VCC-OC to the VCC-LC:
    - De-orbit operations start;
    - Achievement of the correct orbit for RM separation;
    - In case of de-orbit operations missing start at planned time, the ground shall be able to re-plan the activities on a new de-orbit gate opportunity;
    - In case the de-orbit boost is lower than the planned one but the Space Rider is still on a stable orbit, if feasible, the VCC shall be able to program on-board an additional manoeuvre to complete the deorbit and execute a controlled or destructive re-entry.
  - Re-entry and Landing operations: after the black-out phase, the visibility of the re-entry module has to be ensured up to the landing.
- Payloads: several payloads will be embarked in each flight. For each flight, an aggregate of PLs need to be defined considering the different characteristics and needs of each single PL and their adaptability on Space Rider. The operations preparation and execution have then to be in line with the different aggregate of PLs and their needs;
- Data downlink: the planned timeline has to take into consideration and if needed plan the necessary payload data downlink;
- Reusability: there shall be maximum reuse of ground segment and operations concepts established during past LEOP activities and from the heritage of the IXV mission;

- Maintenance: the complete system will be design to support several flights. This implies that not only the system needs to be maintained, but also the operations products need to be revised, updated or new created. In line with that, also the operators need to be up to date with the operations, undergoing further trainings and simulations.

3. Operations Concept

Considering the mission operations drivers, the constraints and the space vehicle design, an operation strategy has been developed specifically for each phase of the maiden flight mission.

3.1 Pre-Launch Phase

The Ground Segment preparation starts about 72 hours before the launch. All ground stations involved in the early operation phase are activated and checked-out. Since this is considered a critical phase, many activities shall be performed under visibility. Thus, four ground stations along the orbit are engaged. Currently the selected stations are Kourou, Singapore, Malindi and Biak.

A voice connection between the Flight Operations Director (FOD) and the representative at launch site is in place in order to allow the spacecraft operations team to be aware of any events of the pre-launch and launch phase, and to provide the spacecraft operation team and GS readiness for launch.

The communication links between the VCC-OC and the PGCC, between the VCC-OC and the Launch Site, as well as between the VCC-LC and the Landing Site are activated and checked-out.

Final dress rehearsal is performed as soon as the spacecraft is integrated on the launcher and on the launch pad. In order to perform the dress rehearsal, the Ground Segment and the operations teams have to be set in their flight configuration. This final test provides the ultimate readiness prior to start the launch countdown in terms of readiness of operations teams and Ground Segment. In particular, the final GSN TT&C (Tracking, Telemetry & Command) network availability checks and rehearsal to the ground stations, as well as final checks on VCC, PGCC and landing site are performed according to the countdown procedure schedule, in order to provide the GO confirmation for launch.

Space Rider system is switched on few hours before the lift-off, in order to perform the final launch chronology. During this time, the TM data monitored by the launch control centre is also made available to the VCC-OC, allowing the spacecraft operations team in MCS and the engineering support team to monitor the SRS configuration for launch according to the pre-launch procedure.

3.2 LEOP and Commissioning Phase

The objective of the GS in this phase is the execution of the LEOP operations, bringing the vehicle from the target orbit acquisition into a suitable configuration in a safe and stable condition in order to start the in-orbit operations.

After the launch, during the ascent phase, since SR-RM transponder is not active, no TM monitoring is executable from the VCC. This TM data is locally buffered and transmitted on ground at a later time. Once Space Rider reaches the target orbit, an handover from the launcher authority to the Space Rider mission authority takes place. The target orbit is achieved autonomously and this event is communicated to the VCC by the launch authority. After that, the control is taken from the VCC-OC and, from this moment, the responsibility of the mission operations is under the FOD.

The first activity to be performed is the acquisition of the first signal from the TT&C stations. It is based on the delivery of either angular pointing data or on the Two-Line Element sets (TLE) previously generated by the flight dynamics system. The TLEs contain mean orbit elements referred to a particular epoch. As a backup, a file with epoch, azimuth and elevation is used. The launcher trajectory dispersions (with an accuracy of $3\text{-}\sigma$) are taken into account by computing the corresponding along-track, cross-track and radial dispersions at the various acquisition epochs by the TT&C stations. Since the largest expected trajectory dispersion is in the along-track direction, multiple scans on the along-track performed.

The first signal acquisition is performed over Singapore ground station, and is essential to be able to monitor and control all the activities performed on-board. The first important activity to monitor is the deployment of the solar panels. This is considered a critical activity, because it starts the power generation, which is devoted to ensure the vehicle autonomy, safety and, therefore, the vehicle ability to perform the whole mission. For such reasons, also the ground operations, devoted to verify and asses their proper execution, can be considered critical in the same way, especially because in case of power generation anomaly, an immediate reaction on ground is necessary. If the beginning of the solar panels deployment is verified by VCC-OC flight operations team during the first visibility window, and a full nominal configuration is confirmed in the next visibility window, it is possible to state the good health of on-board power S/S and that the Early Operation Phase (EOP) operations can continue as nominally planned.

On the contrary, if a failure occurs, it can be detected, most probably, already in the first visibility window. In that case, if the percentage of generated power is above a predefined threshold, the SR remains in its current configuration and the VCC-OC can perform the troubleshooting and reattempt the deployment of the solar panels. In case, instead, the percentage of generated power is below the threshold, an automatic on-board mission abort with a destructive re-entry in engaged. In order to comply with the residual energy of the AOM and RM batteries after the ascent phase, the deorbit boost shall be executed within one orbit from the achievement of the target orbit. Although this activity is automatically performed on-board, since the VCC-OC is able to detect the failure and verify the power level, it has also the possibility to inhibit the execution of the deorbit boost. This operation is very time critical, since in the event, it has to be performed before the activation of the AVUM main engine.

Right after the first acquired passage, when tracking data is available, the flight dynamic system (FDS) engineer generates the first orbit determination, propagates the orbit and generate a set of operational products, including the updated orbital events and pointing data.

The FDS engineer provides to the Joint Space Operations Centre (CSpOC) at Vandenberg the SR ephemeris in order to receive a collision risk management. In case the evaluated risk results not negligible, a Collision Avoidance Manoeuvre (CAM) with the Reaction Attitude Control System (RACS) is planned to either reduce the collision probability or maximize the miss distance at the time of closest approach. The resulting propagated orbit ephemeris are then sent for check to CSpOC for its assessment. After the CSpOC confirmation, the planned manoeuvre can be uploaded and then performed, otherwise the process is repeated again and a new different CAM is planned by the VCC-OC FDS and the corresponding ephemeris sent to the CSpOC for a new assessment.

As far as the first checks are performed, a series of commissioning activities can start. Most of the platform commissioning activities are pre-loaded on the mission timeline in order to be performed automatically on-board. Others commission activities are executed by VCC-OC following the developed and validated FOP procedures. For what concern the commissioning of the payloads, test to be performed will be defined at a later stage, when the all aggregate of payloads to be embarked will be finalized. For these activities, the PGCC is in charge to plan the activities and to transmit the necessary operational products to the VCC-OC for uplink.

3.3 Routine Phase

When the commissioning phase is concluded, the nominal routine phase can start. This phase is dedicated to the platform and payloads operations, and the whole Ground Segment is nominally operational to manage experiments activities:

- the VCC-OC has the mission responsibility and it is in charge to monitor and control the SRS
- the PGCC is responsible of payload activities planning,
- the VCC-LC is active as interface between the VCC-OC and the PGCC, in addition it perform dedicated test with the landing site ground station and is ready to handle an anticipate SRS re-entry.

Most of the activities to be performed during the routine phase are planned in advance. In fact, considering the variety of payloads and their operability, a complex and detailed planning is assessed and prepared prior to the launch and updated during the flight. In order to make the system as much flexible as possible, the management of the on-board activities is demanded to the use of on-board timeline (MTL) and a set of sub-schedules. These contain all the time-tagged commands needed to operate both the payloads and the platform. It is foreseen to use a sub-schedule for each PL and sub-schedules for different activities of the platform, to manage both the nominal operations and the contingency ones. In case of safe mode, for example, a specific sub-schedule is activated to allow to perform only specific activities in order to ensure the safety of the system.

This approach provides flexibility in terms of planning and on-board management, without impacting on the total resources and performance of the system overall (e.g., uplink capacity, activities conflicts resolution).

The platform operations (PF OPS) are planned within the VCC-OC on the basis of inputs from Flight Dynamics, ground stations visibilities and bookings, SRS available resources, and Payload Operations Requests (POR) planned by the PGCC. The requests for payloads activities come directly from the PL users located at the UPOCs. Via the front-end web application of the PLMS within the PGCC, the UPOC users can generate and submit the User Operations Requests (UORs). Once the UORs are submitted to the PLMS, the PL operations team starts the Short-Term Plan (STP) planning session. The planning considers the whole aggregate of payloads and the constraints (as reported in section 2). This activity is performed off-line during working hours and is concluded well in advance of the PL activities execution. The PL operator at the PGCC selects the period of time of the STP to be generated. Nominally, the STP duration is one week. The PLMS automatically translates the UORs into preliminary PORs.

These PORs are then selected by the PL operator and, based on the available SRS resources, activities priorities, PL constraints, and planning rules, can be planned and included in the timeline. The planned PORs are passed to the Mission Planning System (MPS) of the VCC-OC, which integrates them within the general SRS timeline for its uplink on-board, performed by the MCS. The whole planning process is depicted in Figure 2.

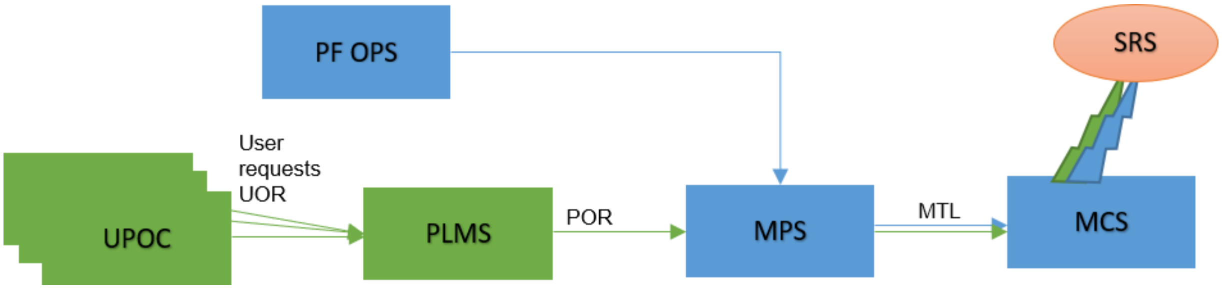


Figure 2 Planning process for the generation of the SRS timeline

During the operations execution, mainly the following activities are performed:

- Uplink of MTL/sub-schedule. Considering the low orbit of SR, the maintenance or contingency operations, can't be executed in immediate way during the visibility period, but are programmed in the TT-TC queue through PUS 11. Therefore, the typical immediate TC operations executed during the identified GS visibility, is the pass management and the upload of the MTL or a stack of Time-tag command, prepared in advance.
  In this case, the real-time evaluation is limited to the check of the correct upload of the TCs in the TT-TC queue.
- Monitoring and Control of SRS will be performed by VCC-OC, both in real-time during the visibility passes and offline through the playback downlinked TM. This data is then analysed in order to calculate the used resources against the available ones.
  The SR platform (both AOM and RM) TM and the payloads HK TM are archived and processed on both VCC-OC and VCC-LC function. The science data is instead delivered to the PGCC after the pass.
  Within the PGCC all the data is stored and let available to the UPOCs for their retrieval. The data let available to the UPOCs include the specific PL data (both HK TM and science data) and auxiliary platform data that the UPOC requests.
- Orbit determination and products generation, including the collision risk assessment and management. In case the probability of collision is higher than the defined one, the collision avoidance manoeuvres are planned, calculated and implemented on-board. The process is the one explained in section 3.2 applicable both for the LEOP and the routine phase. It has to be noted that the planning of CAM shall take into account also the possible payload impacts, trying to minimize the degradation/interruption of the payload activities. In this case the CAM execution is notified and coordinated with PGCC since it can have an effect on the payload experiment.
- The payloads activities and status are monitored by the payload operations team on the base of the received PL HK TM. All the PL data (both HK TM and scientific data) is then forwarded to the UPOC, where the PL users can retrieve it, assess it and provide back new inputs to the PGCC for the planning.
- The platform and PLs activities are planned, and all the operational products are prepared and validated. These include PORs, MTL and sub-schedule, on-board control procedures (OBCP) and TC files to be uplinked.

According to a preliminary plan, the first month of the routine phase is foreseen to be devoted to microgravity experiments. These require a specific attitude mode which guarantee a certain level of micro-gravity. Therefore, during this phase, no manoeuvres are planned (except of possible CAMs). After this phase, an orbit raising manoeuvre, necessary to both restore the SR altitude and to keep low the orbit eccentricity, is then necessary.

It has to be noted that the planned orbit raising manoeuvre is performed by the AVUM main engine, while the CAMs are performed by the AVUM RACS propulsion system. Thus, the overall operative concept is build taking into account the above considerations. In any case, the Orbit Raising Manoeuvre is optimized in a way that the final altitude reached, once propagated during the time, is compatible to a final orbit needed for de-orbiting the vehicle, avoiding thus the need for additional manoeuvres to compensate drag decay effects.

In order always to ensure the safety of the vehicle, possible contingency scenarios have been identified and analysed. Contingency operations are then put in place both on-board and at the ground segment level. On-board a series of FDIR are implemented, and on ground an anomaly process has been defined. The anomaly process starts with the detection of an anomaly, with the subsequent notification to all the involved teams, both ground teams and the engineering support team, specialized in the vehicle subsystems. An anomaly review board (ARB), which includes the ground teams, the manufacturer and the ESA customer, is called. The ARB takes the decision about the contingency resolution.

The identified contingency scenarios include both mission recoverable contingencies that can be resolved and allow to continue the routine operations, and mission not recoverable ones that cannot be resolved on flight and require a quick re-entry. In the first group are included contingencies leading to incapability by ground to acquire the TM/TC link with SR. These are resolved directly by the GS operators applying dedicated available flight procedures. Belonging to the mission recoverable contingencies are also the one involving the on-board subsystems triggered by the FDIR. In order to recover the nominal operations; the GS operators once assessed the problem notify to the ARB. In the case flight procedures are available, they are used, confirmed by the board. In case no procedures are available, the board identifies the proper way for the anomaly resolution, and the GS operators (also with the support of the Engineering Support Team) develop, validate (through the OPSIM) and apply new contingency procedures.

Under the category of the mission not recoverable contingency fall the ones that cannot be resolved on flight and request a quick re-entry. This kind of very severe contingency are precisely coded into Authority Decision Plan and, if it is not the case, the resolution is decided by the ARB. Depending on the severity of anomaly and/or impacted on-board sub-systems, a nominal or destructive re-entry is recommended. A nominal anticipated re-entry is executed in the same way of the nominally planned one at end of mission. Of course, differently from the nominal case, and on basis of the ARB outcome results, it could be necessary to execute some additional and/or different operations to alternatively configure the SR. In case instead, a nominal re-entry cannot be ensured, also to meet the safety constraints, it is necessary to perform a destructive re-entry to manage the occurred on-board severe anomaly.

In case instead anomalies are detected at the payloads level, fast corrective actions can be taken. A short loop planning cycle of two orbits is foreseen. This means that from the reception on-ground of the anomaly detection, the PL operators (together with the UPOCs) have a three hours (two orbits) to assess and react to the anomaly, and uplink the necessary commands. They generate, via the PLMS, a Payload Direct Operation Request (PDOR), which does not follow the nominal planning chain (via mission planning systems), but is directly uplinked by the MCS. In order to speed-up the reaction time for PL contingencies, including the preparation of the PDOR and its verification, these PDORs are pre-agreed (already before the flight) PL sequence/commands. For example, in case during collision avoidance some PLs need to be reconfigured, this will be performed via PDORs.

At the end of the routine phase, with the declaration of the mission end, the payloads are reconfigured in preparation for de-orbit and re-entry. All payloads reconfiguration is exercised by Ground Segment teams following ad-hoc PL procedures. Payload deactivation is payload dependent and can be different from payload to payload and mission to mission. It might include for example payload switch-OFF, payload mode change, payload configuration change. Deactivation of the payloads also includes the reconfiguration of the resources (power, data, thermal) supplied to payloads. Based on PL complexity, the reconfiguration can be done from Ground Segment directly via ground commands or through sequences called out by the MTL.

3.4 De-orbit, Re-entry and Landing Phase (including preparation for de-orbit)

At the end of the routine phase, the Space Rider System (AOM + RM) and its payloads are configured by VCC-OC in preparation for the de-orbit phase. Based on the mission timeline, the last activity of the routine phase is the deactivation of the payloads, in preparation for the de-orbit. From this moment, the responsibility of the mission is transferred from the FOD to the Re-entry Operations Director (ROD).

The Preparation for de-orbit starts with the uplink of the specific command devoted to activate a set of on-board tasks and to allow the VCC-OC flight operations team to perform the necessary on-board sub-systems health verification. Among them, the following high-level tasks are highlighted:

- Chill down of the RM temperatures
- Health status check
- RM radiator closure and verification
- MPCB closure and verification
- RM GNC initialization
- Activation and checkout of the RM safety subsystem
- Wind parameter upload
- AOM reconfiguration and verification for GO conditions for de-orbit

At Ground Segment level, the preparation for de-orbit includes a set of activities performed at different stages already during the routine phase, which include regular propaedeutic checks. In particular, regular checks of the weather forecast are performed in order to be able to start the planning of the de-orbit. In case of adverse weather conditions, the decision authority could decide to postpone the end of the mission and continue with the PLs activities. Check-outs and connection tests with the landing site re-entry ground station antenna are also performed. These tests can be performed every two/three weeks in order to verify the readiness of the antenna and its connection with the VCC-LC, especially for the case of an anticipated re-entry. About seven days before the start of the de-orbit instead a set of on-ground activities which lead to the final authorization for de-orbit are performed. In particular, the weather in the descent and landing area is verified to be within the allowed conditions for landing. The landing site facilities are also checked to provide the authorization for landing.

The re-entry operations team starts the assessment and analysis on the possible re-entry opportunities. Starting from seven days before the de-orbit execution, a set of radio-sounding balloons launches is performed, in order to measure wind parameters at high altitudes (up to 30 km). The measured data is used for the calculation and analysis of the re-entry trajectory. In addition, the sounding data, together with the received weather forecast are used to assess if the weather trend is within the acceptable limits for a re-entry or not.

The re-entry operations team exercises the re-entry flight dynamic system (RFDSS) planners to identify a feasible re-entry opportunity, compute start/stop and duration of de-orbit burn and compute de-orbit burn and separation associated parameters (state/vectors/Keplerian), as well as the re-entry trajectories of both AOM and RM.

This planning process is performed again 48h and 24h prior to the de-orbit execution, and lead to the authorization by the Landing Site Safety Authority (LSSA) to perform the official on-board de-orbit preparation.

After a sounding measurement performed 24h prior the de-orbit execution, the VCC-LC needs the confirmation from LSSA that weather conditions are GO for descent and landing, that the landing site itself and the landing site ground station antenna are ready for landing, and that the on-board de-orbit preparation activities can start according to the on-board timeline. Then, other two sounding and wind measurements campaigns are conducted at minus 4h and minus 1.5h prior the de-orbit execution. At the VCC-LC premises, the re-entry operations team exercises the RFDSS to process the sounding data, provide data for go-no-go decision, generate the wind table for uplink, and generate the atmospheric profile. The products are then validated exercising the entire process with the operational simulator.

During the whole process of planning and preparation for de-orbit, several authorizations (GO) are given from the different parties:

- The VCC-OC provides the readiness of SRS and availability of Ground stations for the de-orbit operations.
- The safety authority (within the VCC-LC) is in charge of providing information on the AOM and RM trajectories to the local Air Traffic Control for the issuing of the notification to the airman (NOTAM) and to the Maritime Control for the issuing of the messages to the navigation (NAVTEX).
- The LSSA provides its authorizations for what concern all the aspects related to the safety at the landing site.
- The landing site responsible person provides the final evidence of the readiness of the landing site for what concern the infrastructures and connection with the VCC, the personnel, the ground station antenna, and the weather conditions.
- The ROD is the final figure providing the authorization, after collecting the above authorizations. He authorizes the planning, preparation, and then the execution of de-orbit after checking the readiness of the Space Rider vehicle, of the VCC-LC and its operators.

The de-orbit phase itself starts with the execution of the command which allows the execution of the de-orbit sequence, which includes the actuation of the manoeuvre boost. This command is sent under visibility. The sequence of operations from the de-orbit till the landing is nominally autonomously executed on-board, however, in case of unexpected problems, the VCC has the capability and the authority to halt the execution of the de-orbit manoeuvre at any time during a visibility window, before activation of the AVUM main engine. With the de-orbit sequence command, the on-board AOM algorithm starts to compute autonomously the de-orbit boost conditions (this will be partially performed under visibility) and both AOM and RM start to be powered only by the batteries, while the solar panels are oriented in the de-orbit configuration. When entering in the next visibility, the de-orbit boost starts, with the consequent AOM slew and RM pointing leading to the separation.

Considering that de-orbit is a time critical phase, no SAFE Mode transition is foreseen to allow the Ground Segment to recover the nominal mission. For this reason, a specific mission abort mode FDIR has been introduced to trigger the abort of the mission in case of failures that are not recoverable / manageable from ground and for which a real time recovery is required. The identified failure scenarios are related to a too high or too low boost of the de-orbit manoeuvre. The recovery to these failure scenarios implies a mission abort and it requires the execution of a destructive re-entry sequence to be completed within the duration allowed by the residual power in the on-board batteries. These failure scenarios are detected by the AOM OBSW which activates the execution of a destructive pre-planned de-orbit manoeuvre.

In case instead, the de-orbit is nominally executed, after separation from the RM, the AOM performs the manoeuvres required for collision and contamination avoidance to avoid any impacts with the RM. A final boost autonomously computed by AOM on-board computer is then performed in order to ensure the AOM destructive re-entry in the Ocean.

As on basis of de-orbit timeline, these activities are planned under the last visibility, and the VCC-OC acquires the AOM trajectory information and verifies that the AOM re-entry trajectory, up to the end of the visibility, is in line with the planned one. During this phase, no commanding to the AOM is possible.

After separation from the AOM, instead, the RM autonomously executes the entire coasting, re-entry and descent sequences. The coasting and the attitude stabilization is visible from the ground station for about four minutes.

At the separation between AOM and RM, once satisfied the conditions described in section 2, relevant to the de-orbit operations handover, the operational responsibility is transferred from the VCC-OC to the VCC-LC. The spacecraft operations team at the VCC-OC monitors the AOM destructive re-entry, while the re-entry operations team at the VCC-LC monitors and controls the RM re-entry.

After the loss of signal of the last de-orbit ground station, the Ground Segment configuration changes to a direct connection between VCC-LC and landing site ground station to monitor and control the re-entry of RM.

After the coasting, the RM enters the atmosphere going from hypersonic to transonic flights with the subsequent triggering of a subsonic parachute deployment, followed by the deployment of a guided parafoil. The parafoil is guided by the on-board GNC, which allows a very precise and safe re-entry and landing, ensuring experiments return from the orbit back to the earth.

Those phases are designed to be fully autonomous, nevertheless, it is necessary to provide updated wind parameters to the GNC system for its precise autonomous guidance. Wind table commands are uplinked by VCC-LC to the RM only after the end of the blackout phase when the link with the ground station at the landing site is established. Since at the exit of the black-out it is expected a large azimuth and elevation trajectory dispersion, it is necessary to perform the RF acquisition again. RM is in visibility of the re-entry landing site ground station. It rises from the horizon and it is at 800-900km distance. A signal scanning method in azimuth, pointing at different elevations might be used in order to find and then lock the signal. In order to facilitate the re-acquisition of the signal, the RM transponder is also set to high power mode. After the link with the ground is established again, the VCC-LC sends a command to change back the transponder in low power mode, according to the ITU regulations, not to irradiate with high power the ground. The strategy for this acquisition is currently being evaluated and developed.

During the whole re-entry, till the landing, the VCC-LC monitors and propagates the RM trajectory and its behaviour on the basis of received real-time TM data and coordinates the activities with the landing site in preparation for RM landing. During the final approach before the landing, the RM landing gears are deployed and the system is preparing its landing.

During the re-entry phase, it can still happen that the RM does not follow the nominal corridor trajectory, but exit its boundaries. Both the re-entry operations team at the VCC-LC and the LSSA are able to detect such contingency, in an independent way.

In case the RM trajectory goes outside the nominal boundaries and consequently poses potential safety hazards, a dedicated "neutralization" command is available to be sent. This dedicated "neutralization" command is sent by LSSA via a dedicated channel independent from the VCC-LC one, and forces the actuation of the parafoil bridles cutters, with consequent fall down of the RM in the ocean.

3.5 Post-Landing Phase

After its landing, the RM is maintained switched-on for up to a couple of hours, in order to allow all the health and safety checks, before letting the people accessing the vehicle. In fact, in order to allow people to approach and access the vehicle and its MPCB, three safety authorizations are foreseen: to approach the landing area, to approach the vehicle and to access directly the vehicle. These authorizations are provided by a dedicated Post-Landing Ground Safety Authority on the base of the vehicle TM sent from RM to the landing site ground station. During this time, part of the monitoring includes also the temperature at the interface plate with the payloads inside the MPCB. This is particularly important for some biological payloads that require to maintain their samples within a certain range of temperatures.

Once these first safety checks are performed, the RM can be switched-off. This can be performed both in remote, by the VCC-LC and thought the umbilical connected to the ground support equipment (EGSE) at Landing Site.

After the system is switch-off, it is accessible by the specialists, and the payloads that require early retrieval can be extracted and delivered to the PL users.

The different systems of the Ground Segment can be decommissioned and deactivated, together with their interfaces. Before doing that, the VCC archives are aligned and the PGCC receives and archives all the data contained on the SR mass memory retrieved manually by the specialists on site.

3.6 Post-Flight qualification and preparation for next Flight

Before the transition to exploitation phase, a dedicated lesson learned is prepared. The VCC-OC, VCC-LC and PGCC operations team analyse all the subsystems and their interfaces with other systems in order to update the necessary elements. Updates are evaluated also for what concern operations processes and procedures.

In the following, activities to be performed for the preparation of the subsequent flights are described. For each flight, the MPCB might contain different sets of payloads. In order to reduce the turn-around time between landing and the subsequent launch, some pre-integration activities are executed in parallel.

Operations products related to SRS, consolidated during the first flight, are revised and refined during this phase, for the subsequent flights.

Additional products are generated and added according to the specific needs of the different payloads and the different orbit selected.

The operation products preparation/update includes:

- Revision of SRS nominal and contingency procedures (based on lesson learned from previous flights), and update to consider the new orbit, mission PF and PL requirements and possible platform maintenance.
- Support to simulator update to include the new PLs set
- Definition and preparation of the new set of PF/PL procedures
- Update the training material to include potential PF/PL specific activities
- Timeline/plan preparation
- Support to the new database re-integration, re-testing and re-validation in the VCC-OC, VCC-LC and PGCC systems.

In addition, possible new personnel undergoes the complete training and the process for the certification. The personnel already involved in the previous mission, instead, refreshes some details and gets updated on specific aspects related to the new mission, getting new certification.

4. Conclusions

In this paper it has been presented the Space Rider Ground Segment Operations Concept, which has been developed for each phase of the mission, from the pre-launch, to the post landing. The operations strategy considers the mission objectives, the drivers and the different constraints. Several processes have been defined in order to cope with the conduction of both the nominal and the contingencies operations of the vehicle, and of each single embarked payload. The processes include the planning of vehicle and payloads activities, the conduction of the critical operations especially during LEOP and during the de-orbit, re-entry and landing. They include also the management of orbital manoeuvres, the collision avoidance, and the de-orbit ones. At ground level, the operations strategy focuses on the VCC and PGCC configuration and usage, as well as the management of the whole ground stations network, for the successful uplink and downlink.

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