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The AVUM Orbital Module for the Space Rider System

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Abstract
The Space Rider System is the new affordable reusable European space transportation system launched by the ESA VEGA-C launcher. It is able to perform experimentation and demonstration of multiple future application missions in Low Earth Orbit and safely be recovered on ground.
The Space Rider System (SRS) is a complex Spacecraft made of the AVUM Orbital Module (AOM) and the Re-entry Module (RM) integrated in a single stack-up.
• The AOM consists of the modified AVUM+ and of the AVUM Life Extension Kit (ALEK) and acts as service module during the orbital phase;
• The RM is the lifting body based on the IXV demonstrator, which carries the experimentation payload inside the Multi-Purpose Cargo Bay (MPCB) and will return to Earth for landing and re-flight
This paper describe the architecture and the functions of the AOM.

1. The Space Rider System

The Space Rider System is a complex space system made of two Modules: the AVUM Orbital Module (AOM) and the Re-entry Module (RM) integrated in a single stack-up.

• The AOM consists of the modified AVUM+ and of the AVUM Life Extension Kit (ALEK) and acts as service module during the orbital phase;
• The RM is the lifting body based on the IXV demonstrator, which carries the experimentation payload inside the MPCB and will return to Earth for landing and re-flight.

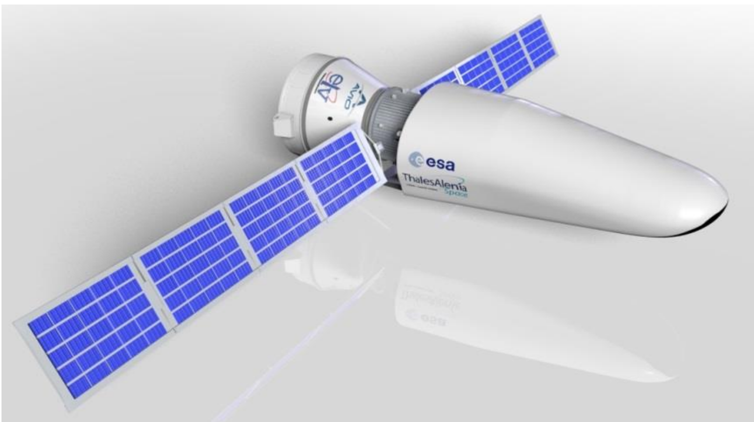

Figure 1: Space Rider System

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The SRS is launched on top of the Vega C launcher.
It is able to flight for more than 2 months carrying out several experiments in its Multi-Purpose Cargo Bay that offer standardized services of power, data link and thermal control to the hosted Payloads.
It is design to have an extended flexibility in terms of attitude, pointing accuracy and high grade micro-gravity free-flying environment.

After the accomplishing of the orbital mission the SRS is injected in a decent trajectory that targets the selected landing site, the two Modules are separated: the RM stars its gliding towards the landing site, while the AOM re-ignites its main engine to tune-up a safe destructive re-entry in open ocean waters.

The System is completed by the Space Rider Ground Segment that includes:

- The Mission Control Center (MCC), integrating:
    - The In Orbit Control Center (IOCC)
    - The Payload & Landing-site Control Center (PLCC)
- The Ground Stations Network
- The Landing sites
- The Logistics and Transportation facilities

The Space Rider System is designed to operate at an altitude of 400km and it is able to span form almost equatorial to sun-synchronous inclinations, offering up to 1.2m^3 of useful volume for payloads.

2. AOM Functions

The AOM is in charge to supply the power to the whole SRS and performs all the orbital manoeuvres up to the separation of the two modules (AOM & RM).

AOM will start its operations after the initial orbit acquisition at the end of the Launch Vehicle ascent phase as for standard VEGA-C flight.
In the ascent phase the AVUM+ still act as a standard 4th stage of the VegaC Launch Vehicle.
During the ascent phase the ALEK avionics is not functional, the whole mission management is managed by the AVUM+ avionics and the Flight Program Software A running on the launcher's On Board Computer.
After the target orbital acquisition the handover from VegaC's On Board Computer to the AOM On Board Data Handling, occurs. The AOM begins functional as part of the Space Rider System

Table 1: AVUM+ function in the SRS

Flight Phase	AVUM$^+$ Function	System
Ascent Phase	As standard 4th stage	LV
Orbital Phase	Part of AOM	SRS
De-orbit SRS	Part of AOM	SRS
De-orbit AOM	Part of AOM	AOM

The ALEK avionics is initialized, the Launcher's OBC is switched-off.
The Solar Arrays are deployed and the first mode transition is commanded to Sun Acquisition Mode.
The RM starts its initialization sequence. The SRS begins its commissioning phase.
After the SRS is fully operative in orbit the PL commissioning may start.
By means of its On Board Software, the LPS (Liquid Propulsion System), the RACS (Roll & Attitude Control System), the RWA (Reaction Wheels Assy) and the Magneto-torques rods, it will ensure the attitude and orbit control manoeuvres during the Operational Phase. The Navigation function is performed collecting and merging the data from the available navigation sensors' suite: 2 Star Trackers, GNSS, 6 Sun Sensors, 2 Magnetometers and the IMU.
At the end the Operational Phase the AOM will boost the RM in its descent trajectory toward the landing site. Besides, after the separation it shall be able to secure its Impact Point far away the landing site in open oceanic waters.

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3. Mission Description

The Sapce Rider Mission Typical Mission Sequence is the following:

- Launch and Ascent Phase
- LEOP & Commissioning
- Microgravity Operational Mode
- Altitude Control Maneuver
- IOD/IOV Operational Mode
- Deorbiting of the Re-entry Module
- Safe splash down of the AOM
- RM Landing
- Payload Recovery and Fast Exploitation

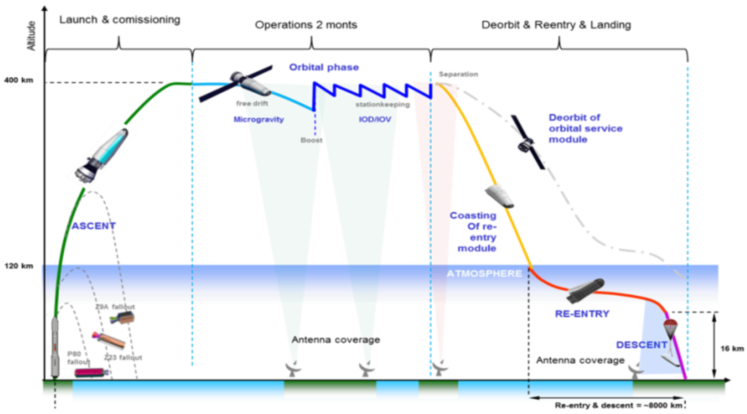

Figure 2: Space Rider Typical Mission Sequence

For measure the performance of the system a Refrenc emission sequence has been created in order to evaluate all the possible operative modes in a single mission.

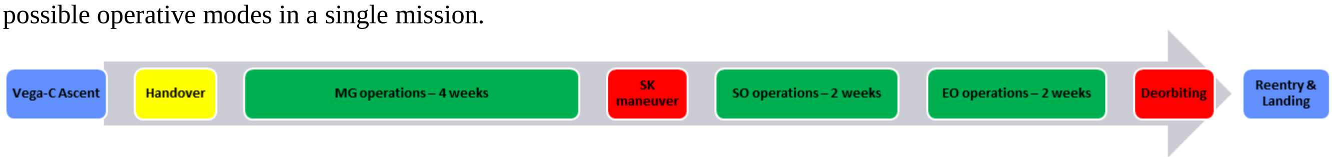

Figure 3: Space Rider Reference Mission Sequence

The orbital phase is the core of the mission. It starts few seconds after the AVUM+ circularization boost cut-off allowing the handover between the launcher's OBC and the AOM OBDH as well as the starting of different AOM equipment (Avionics, Sun sensor orientation, Solar arrays deployment…).

After the commissioning phase, a typical reference mission is the following:

- four weeks in micro-gravity,
- two weeks for Space observation,
- two weeks for Earth observation.

The micro-gravity phase is characterized by an attitude minimizing the control efforts. The baseline is Nose to Nadir orientation while ensuring the Sun following of the Solar arrays. Optionally the switch off of the control functions is ordered to reduce the possible vibrations induced by the RW. In this case the attitude is no more predictable over a too long horizons. The control is thus be periodically reactivated.

The Space Observation is characterized by a Bay to Zenith orientation while ensuring Sun following of the solar arrays. A variant can be a customer-defined orientation in Space.

The Earth Observation is characterized by a Bay to Nadir orientation while ensuring Sun following of the solar arrays. A variant can be a customer-defined orientation of the Bay wrt Nadir (tilt of the bay).

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These main long phases can be interrupted by raising boosts in case the altitude decay is deemed to high (depending on the mission needs, on the attitude history and on the actual atmospheric conditions).

These main phases can also be interrupted by Safe modes. In case of FDIR conditions of any level, the AOM can be requested to be put in Safe mode waiting for a resolution of the problem (switch off or re-initialization of equipment, redundancy management…).

The ground intervention during this orbital phase is permanent to:

- send the commands to the AOM and to the experiment if need
- monitor the AOM status (FDIR, reconfiguration, emergency avoidance manoeuver…)

After the Orbital Phase the vehicle shall re-enter to Earth, to manage it a dedicated phase is defined for this part of the mission.
The Re-entry Phase is composed of two sub-phases:

- a de-orbiting boost followed by a separation to put the RM on an orbit with a specified perigee allowing the atmospheric re-entry and the landing on a given landsite. The boost is done at a given orbital position during a possible window (the re-entry is not feasible at each passage),
- a Collision Avoidance Manoeuvres (CAM) and successive boosts (1 or 2) to allow the re-entry in oceanic waters away from landmasses as in a classical VegaC mission.

4. AOM Architecture

The AOM, as service module of the Space Rider System, shall accomplish several functions devotes to keep in obit the SRS for two months, ensuring the Attitude and Orbit Control and the power supply. It is itself a complex spacecraft made by:

- AVUM+ (as is from VegaC with minor adapting)
- ALEK Assy
    - PLA1194-LEK (VG-1194 conical adapter modified for Space Rider)
    - ALEK (AVUM Life Extension Kit)

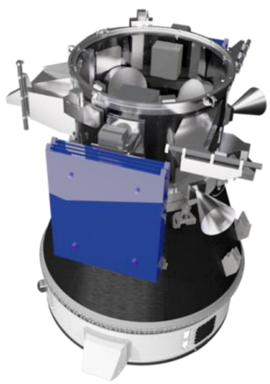

Figure 4: AOM with SAW in stowed configuration

AVUM+ is the 4th stage of VEGA-C LV, it has minor modification in order to implement the Thermal Control System (TCS) managed by the ALEK.

The ALEK module is the version 2 (ALEK2) of the VSS ALEK family. The ALEK module hosts the avionics dedicated to the Orbital Phase Operations and the Power S/S.

In order to properly connect AVUM+ with ALEK a modified version of VG-1194 PLA has been developed

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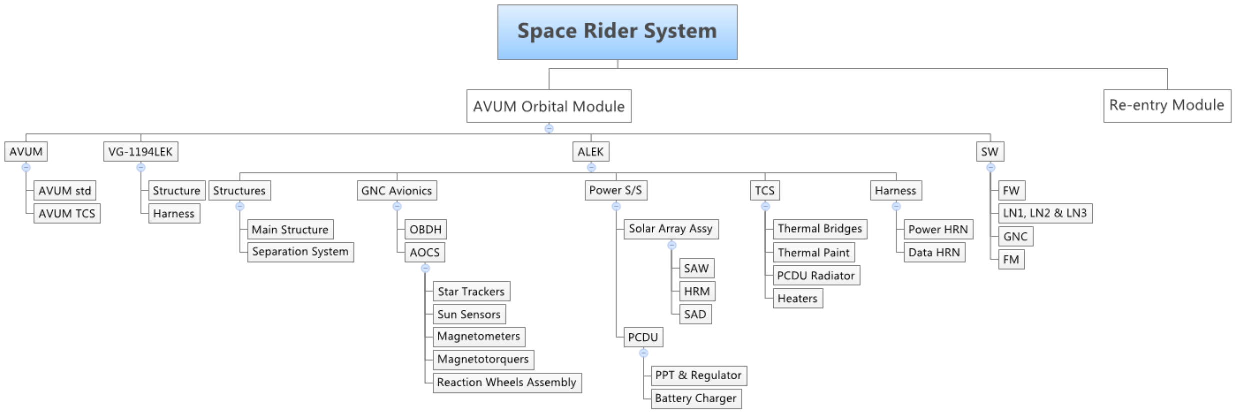

Figure 5: AOM Product Breakdown Structure

AOM main characteristics:

- High efficiency Solar Generator for up to 3.6kW of installed power (up to 2kW deliverable to RM)
- Multiple Attitude Control Actuators for wide range of maneuvers
- Reaction wheels for smooths and precise maneuvers
- Chemical RACS for fast maneuvers and small scale orbit control
- Magnetic rod for smooth and continuous perturbation counteracting
- Orbital Control based on well proven Vega’s 4th stage Liquid Propulsion System
- Complete Navigation’s sensors suite for high accuracy performances
  - Star Trackers
  - Magnetometers
  - Inertial Unit
  - GNSS
- Powerful On Board Data Handling system properly designed for orbital operations
- Maximum reuse of VegaC 4th stage for cost and development schedule optimization

4.1 AVUM+

The AVUM Orbital Module reuses as maximum extend the AVUM+ stage Subsystems. Only the launcher’s On Board Computer is switched off after the ascent phase and the target orbit injection. During the Orbital Phase and the Re-entry Phases its function is replaced by On Board Data Handling of ALEK that takes the control also of the AVUM+ Subsystems: the Liquid Propulsion System and its Thrust Vector Control, the Roll Attitude Control System and the Central telemetry Unit.

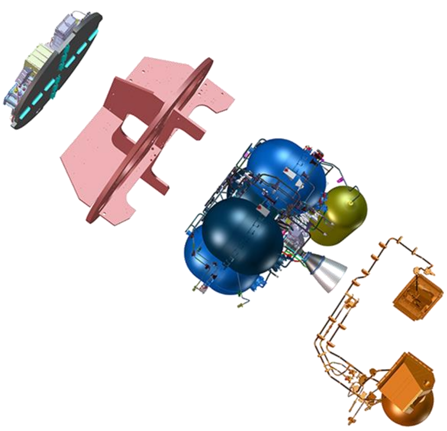

Figure 6: AVUM+

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AVUM+ is the VegaC upper stage for orbital positioning and attitude control. The AVUM+ stage consists of two different sections – one that hosts the propulsion system (APM: AVUM Propulsion Module), and the other which is devoted to the platform that houses the avionics (AAM: Avum Avionics Module).
The APM provides attitude and axial thrust control for the VegaC Launcher during the final stages of flight, in accordance with mission requirements. The current standard configuration includes a liquid bi-propellant system for primary manoeuvres which uses nitrogen tetroxide (NTO) as the oxidant and unsymmetrical dimethyl hydrazine (UDMH) as the fuel – both propelled by pressurised helium gas – and a monopropellant RACS for attitude control. Total propellant load varies from 460 to 740 Kg, depending on configuration and mission. The AMM avionics module hosts the main components of the launch vehicle's avionic subsystem.

Table 2: AVUM+ characteristics

AVUM+ Main characteristics
AVUM Diameter 1.9 m Propellant mass 740 Kg Mass of inerts 590 kg Motor mass 16 kg Average thrust of the main motor 2.5 kN Specific impulse 314 s Combustion time: 940s

No major changes are needed to adapt the AVUM+ to the longer orbital life, except for the Thermal Control System that has been redesigned in order to keep the LPS always in its operative temperature range also for critical attitudes. The rationale behind the whole AOM development has been to avoid any constraint coming from the housekeeping of the spacecraft toward the payloads operations.

The batteries of the AVUM+ are also used to power the ALEK's units and shall be recharged by the AOM Electric Power Subsystem.
The Central Telemetry Unit of the AVUM+ serves also the ALEK collecting its telemetry. During the Orbital Phase the telemetry is dispatched toward the RM that provides the downlink to Ground, while for the Re-entry Phase when the two module are separated the CTU is used to transmit the AOM telemetry to ground.

4.2 ALEK

ALEK is the AVIO's New Concept of scalable space module part of the Vega Space System.
It enhances the Orbital Life of AVUM+, the 4th stage of Vega C LV, form few hours to more than 2 months. Its architecture is mostly based on COTS for best cost effectiveness and fast development scheduling. The new developments are limited to Structures (ALEK cylinder and new reinforced PLA1194), the OBDH and Electric Power Subsystem. These new developments maximizes the use of existing European heritage and are based on consolidated technologies in order to reduce the development risks.
To further extend the cost and planning optimization a synergy between the two modules with unique supplier for common HW has been adopted (OBDH and PCDU)

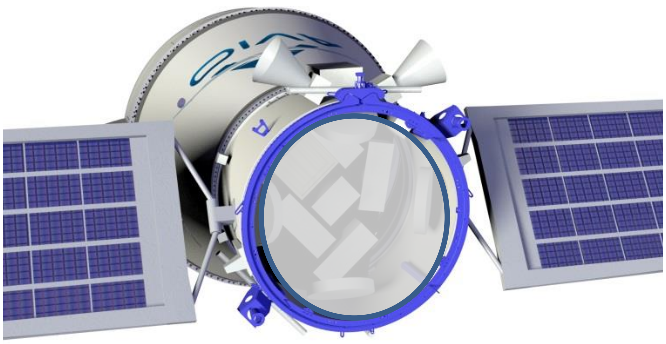

Figure 7: ALEK

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The ALEK is composed basically by primary structure, a CFRP skins honeycomb cylinder of 1194mm radius with an upper separation flange (to separate the RM before the re-entry), an aft flange interfacing the PLA-1194LEK, the attachment point for Solar Wings SAD and several Avionic units fixed on the cylinder:

- Power Conditioning and Distribution Unit
- On Board Data Handling unit
- AOCS
- Thermal Control system

The attitude control and orbital detection is performed on behalf of a set of sensors:

- 2 Star trackers
- 6 Sun Sensors
- 2 Magnetometers
- IMU+ GNSS

and associated actuators:

- 3 Magnetic torque rods
- 4 Reaction Wheels

The ALEK may be also equipped with an optional forward flange interfacing to Vega C adapters (f.i. SSMS adapter).

4.4 PLA 1194

The PLA-1194 LEK is the conical structure that connect the AVUM+ stage with the ALEK and is composed by:

- a truncated cone structure
- a forward flange interfacing ALEK module of diameter 1194mm
- an aft flange interfacing the launcher of diameter of 2000mm
- a protection membrane to separate the AVUM+ avionics bay from the ALEK
- support elements for the electrical items
- Attachment point for Solar Arrays HRM

Figure 8: PLA1194-LEK

4.5 Electric Power Subsystem

The AOM EPS is built around a PCDU (Power Conditioning and Distribution Unit) with as energy source a two wings Solar Array (each one equipped with a SADM) and supplying both AOM internal equipment and Re-Entry Module via a dedicated primary power bus.

The photovoltaic network of the SA (Solar Array) is divided into several sections themselves composed of several strings in parallel (each string is equipped with a protection diode). Each individual SA section is coupled to an elementary S3R (direct energy transfer Sequential Switching Shunt Regulator) of the PCDU.

S3R is the best topology in term of both power transfer efficiency and mass/volume/cost limitation.
All S3R are commanded by a MEA (Main Error Amplifier) which controls the power delivered to the RM (Re-entry Module) via the main bus.

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The AOM PCDU delivers power to:

- AOM ALEK equipment through LCL protected primary power lines (with 26V-33V unregulated bus)
- AOM active thermal control heaters lines through LCL protected group of switches
- Re-entry Module input power interface with 100V unregulated primary bus.

and is also in charge of:

- the management of the AVUM+ Li-Ion batteries
- providing pyro-like lines for AOM Solar Array deployment
- embed the electronic in charge to command and control each Solar Array wing SADM.
- EPS Command & Control interface with AOM avionic through MIL1553B serial digital data bus and for some telemetries via discrete analog or digital signal lines.

The EPS is able to generate up to3.6kW and to delivers up to 2kW to the Re-Entry Module.

The batteries for AOM power storage to power the Module during the eclipse phases are installed in the AVUM+.

4.6 OBDH

The On Board Data Handling concept is built around a platform controller and a large scale companion FPGA that controls peripheral functions and handles OBDH communication interfaces. The FPGA is connected to the platform controller by an internal SpaceWire link.
In the standard configuration of the OBDH, memory blocks used for OBSW storage, boot memory, and safeguard memory will be connected to the FPGA while memory blocks used for working memory and BIOS are connected to the platform controller.
Furthermore, the OBDH contains UART (RS422), CCSDS TM/TC, SpaceWire, JTAG, CAN, MIL1553, analog and digital IO interfaces distributed between a Processor Module (PM) and an Extension Module (ExM)

On the OBDH’s processor run the On Board Software that manages all the on board operations and can control all avionics of the ALEK and by the connection to the AVUM+ Multi-Functional Unit (MFUmk2) is able to command the whole AVUM+ subsystems.
It is connected to the On Board Computer of the RM in order to communicate with the Re-entry Module, receive Telecommands from ground, dispatch to the RM the AOM telemetry during the Orbital Phase, receive the Mission Timeline with the sequence of the Modes required by the PL, co-manage with the RM OBC the FDIR and safe mode transitions.

6. Conclusions

The Space Rider System is an unique opportunity for Europe to fill the gap respect to the major space players in the field of multi-purpose reusable vehicles. The European approach based on the maximization of the existing heritage developed on different programs allows to shorten the development time and to cut the Non-Recurring Costs. This approach led to the massive reuse of well proven flight technologies and vehicles such as AVUM+ and IXV. The current design of the SRS is a relevant consequence: two modules that maximize the existing heritage. For the Avum Orbital Module, the re-use of the AVUM+, with minor adaption, allows to rely on the parallel production of the 4th stage for the VegaC launcher with a large benefit in term of recurring costs. The ALEK module has been thought with a modular philosophy to be used also in different applications inside the Vega Space System to enlarge is production and consequently reduce the recurring costs. Cost, reliability and schedule also driven the choice of the sensors and actuators embarked on ALEK, all COTS flight proven and available. Only few development where necessary for the main structures, the Electric Power Subsystem and the On Board Data Handling. For all of those S/S the collaboration with partner with strong heritage in similar applications, guaranteed the availability of the necessary technology and minimizing the risks.
The AOM is indeed a flexible service module, capable of deliver to the RM up to 2kW of power and keep practically all possible attitudes guaranteeing the necessary sun following with the degree of freedom of the Solar Array Drive and the rotation around one of the space craft axis when required.
The SRS is presently facing its CDR and it is schedule to have the Maiden Flight on the first quarter of the 2022.

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