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From IXV to Space Rider :
CMC Thermal Protection System evolutions

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Abstract

Space Rider is an ESA program with the objective of providing a reusable unmanned space laboratory with return capabilities to be operated up to two months in orbit. This vehicle is being developed on the basis of the Intermediate experimental Vehicle (IXV) atmospheric re-entry demonstrator which successful flight took place on February 2015.Within the scope of this program, ArianeGroup is in charge of the Thermal Protection System (TPS) of the windward, hinge and nose assemblies of the vehicle. This development relies on the windward and nose assemblies TPS previously developed, tested, justified, produced and integrated on IXV. Ariane Group uses a SepcarbInox® Ceramic Matrix Composite (CMC) to provide a high temperature resistant non ablative outer mould line (OML) of the TPS for enhanced aerodynamic control.

After a reminder of the IXV concept and mission, this paper describes the main requirements and new challenges to develop the Space Rider TPS in comparison with those of the IXV (new aerothermodynamic loads, long orbit life, landing concerns, reusability and refurbishment).

1. Introduction

Space Rider is an ESA program with the objective of providing a reusable unmanned space laboratory to be operated up to two months in orbit before returning the payload to the Earth. This vehicle will be developed on the basis of the Intermediate experimental Vehicle (IXV) atmospheric re-entry demonstrator which successful flight took place on February 2015.

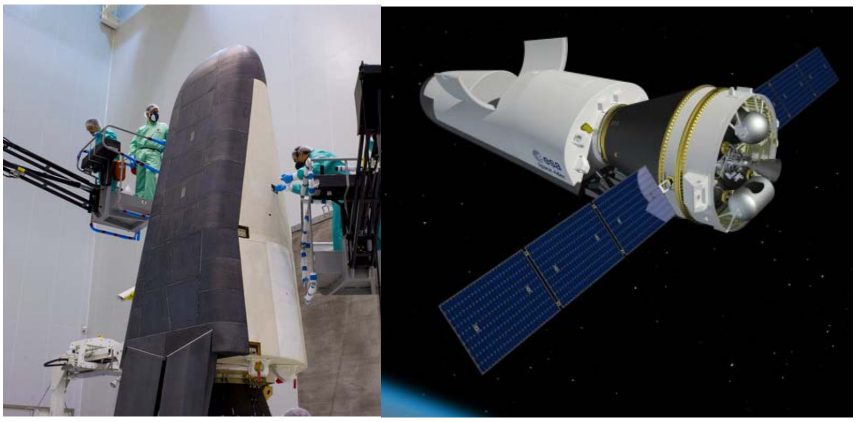

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Figure 1 - IXV and Space Rider (©ESA)

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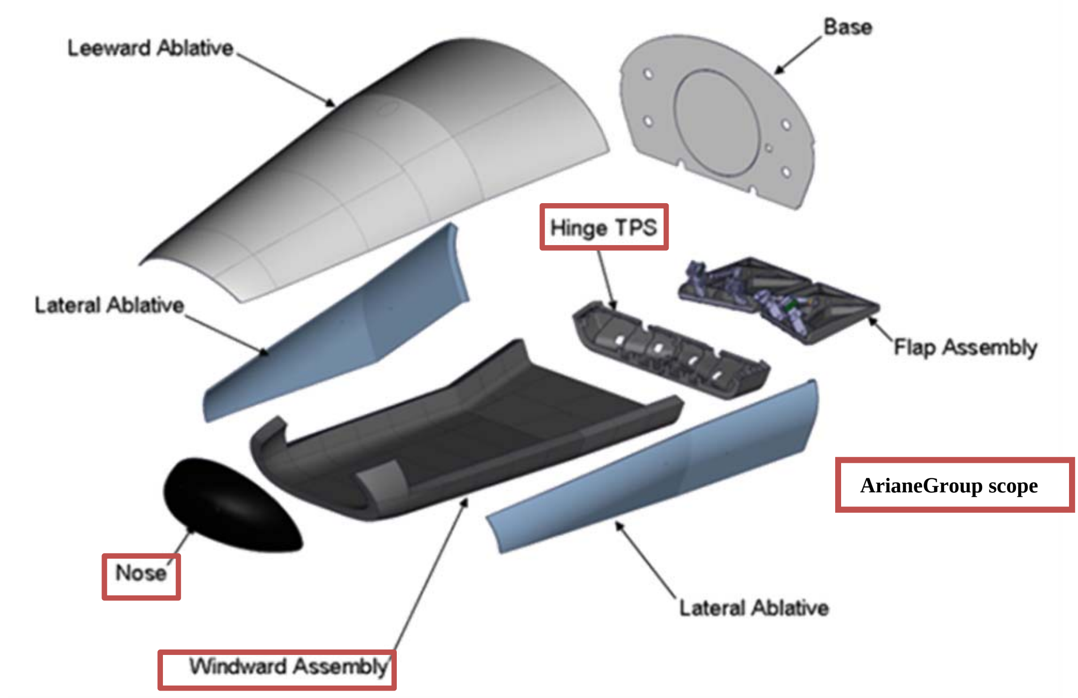

Figure 2 - Space Rider thermal protection and ArianeGroup Scope

After a reminder of the IXV concept and mission, this paper describes the main requirements and new challenges to develop the Space Rider TPS in comparison with those of the IXV (new aerothermodynamic loads, long orbit life, landing concerns, reusability and refurbishment).

2. IXV and Space Rider TPS concept

The TPS concept developed by ArianeGroup is based on the "shingle design", which dissociates thermal and mechanical functions. A thin, heat resistant and structural shell made of ceramic matrix composite (CMC) is designed to withstand mechanical loads due to extreme heat fluxes while maintaining the outer aerodynamic line of the vehicle. And layers of insulation material underneath this skin absorb the heat load, and protect the cold structure from high temperatures (see Figure .)

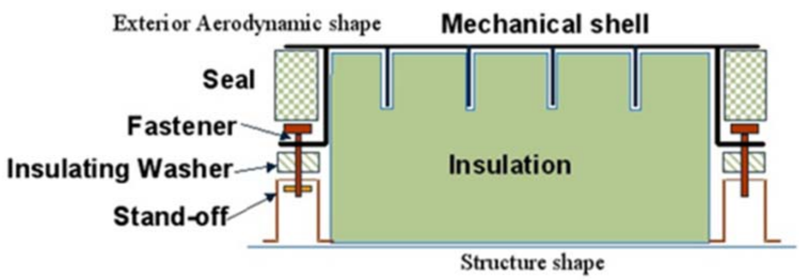

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Figure 3 - TPS concept

The 2 main advantages of this concept are that the CMC is re-usable (Shingles TPS can withstand many re-entries), and CMC and insulations mattresses are light-weight materials, which guarantees low weight TPS for the vehicle.

TPS of IXV and SR are made of three main components: CMC skins, insulation material and attachment system. The outer skin of the TPS is made of Carbon – Silicon Carbide (C-SiC) material. There are 30 panels for the windward (see Figure 3a), made of a thin outer layer with integrated stiffeners and attachment legs and one very large (>1.3 m wide), monolithic C-SiC part for the nose with integrated stiffener and attachment legs.

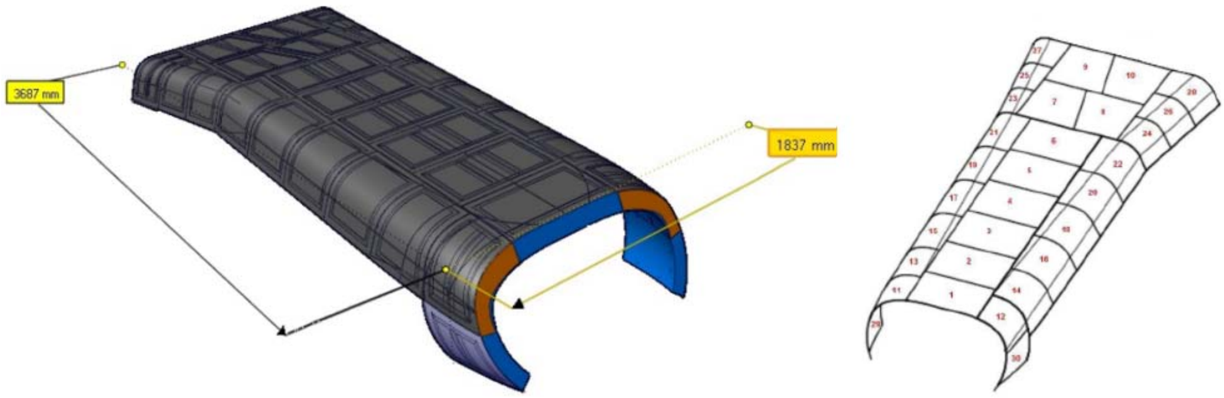

Figure 4a –IXV Windward TPS

Each panel is equipped with insulating materials. Different materials are used, selected for their density, maximum allowable temperature and efficiency, from alumina blankets close to the outer surface to silica aerogels close to the cold structure. Those layers are encapsulated in light polyimide films to prevent dust release, and have patterns that do not match the Windward pattern to prevent air infiltration from the airflow directly to the cold structure. Interfaces between panels are filled with peripheral seals, made of alumina fibres encapsulated in a braided heat-resistant sleeve made of ceramic fibres.

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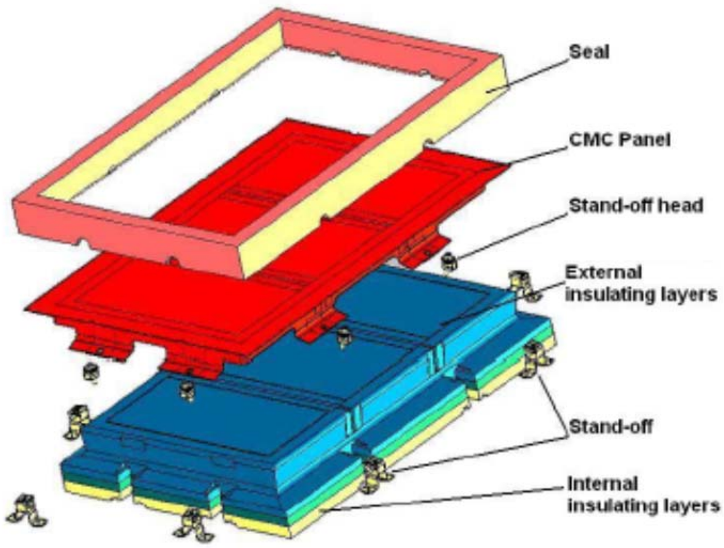

Figure 4b - Split view of a windward TPS panel with insulation and seal

The Panels are attached to the cold structure using specially designed “stand-offs” (see Figure 5).

Figure 5 – Stand-off

They are made of metallic parts, designed to accommodate thermal distortion of the panel, while withstanding re-entry mechanical loads. These stand-offs also have a fastening system with ceramic washers that act as a thermal barrier to prevent structure overheating. The nose is attached to a metallic ring using 16 stand-offs .These stand-offs are designed to accommodate thermal expansion of the nose while withstanding mechanical loads. A metallic dome is fastened to the ring, and provides support to the insulating layers. The ring is equipped with brackets, which are then used to attach the nose to the cold structure.

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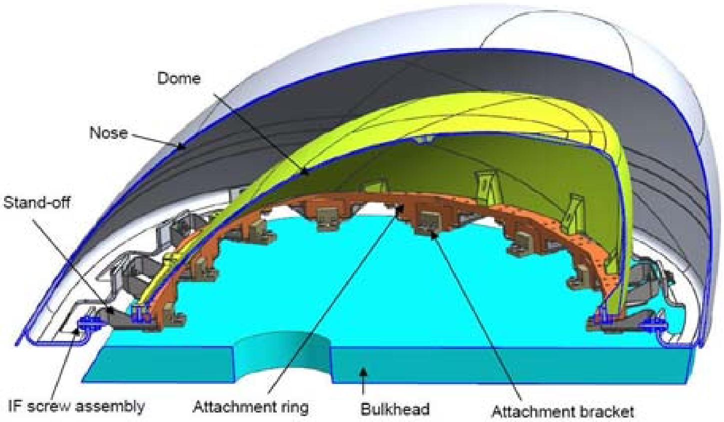

Figure 6 – Nose assembly

Beyond the parts already designed for IXV ArianeGroup is in charge of the Space Rider Hinge structure. This complex shaped part will be produced using the same concept and materials as those of the IXV windward panels.

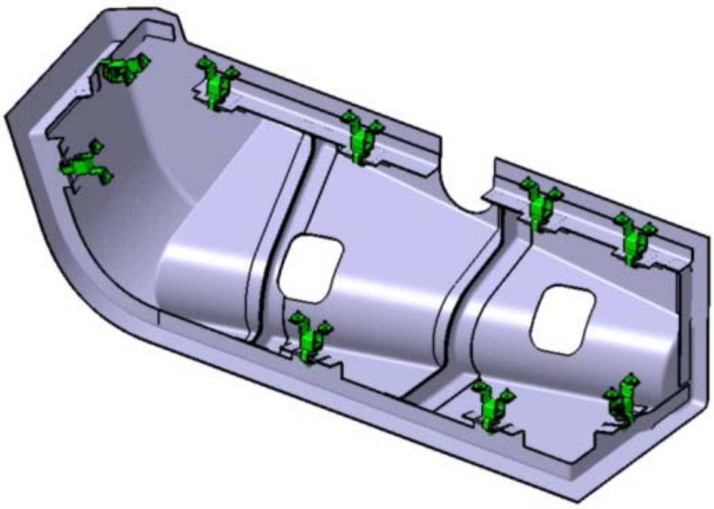

Figure 7 – Half hinge assembly

3 IXV vs. Space Rider mission

The IXV objective was to demonstrate the re-entry performance of the vehicle, so the re-entry occurred after a sub-orbital flight.
Based on this success the mission of Space rider will be to stay up to 2 months in orbit for experiments and then to perform a successful re-entry. In addition the vehicle is planned to be used 6 times with only minimum maintenance between 2 flights and the IXV splash down will be replaced by a ground landing to avoid shocks and contact with salt water, thereby allowing further reuse of the hardware.
Even if the TPS material and geometry remain identical these new objectives lead to design adjustments and a large update of the justification.

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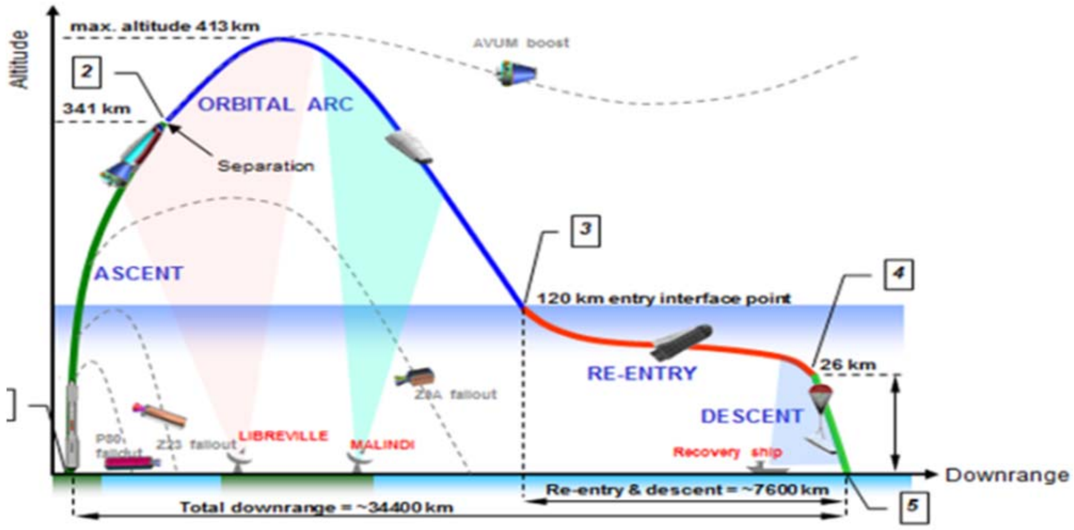

Figure 8 – IXV mission

4 Space Rider new requirements and challenges

4.1 New aerothermal flux

On one hand the IXV post flight analysis confirmed the heat flux specification was overly conservative by about 30% (mainly by assuming a 100% wall catalycity).On the other hand the IXV aerodynamic profile and re-entry conditions will remain the same for Space Rider but the mass will increase by about 30% due to the payload. With the combination of these two effects the actual Space Rider heat flux will be similar to the over-specified IXV one.
This point has been confirmed by AGS analysis with a similar maximum temperature on TPS during re-entry on both vehicles
So this confirms the IXV thermal protection's ability to withstand the Space Rider reentry conditions.

4.2 Life in orbit

The 2 month orbit phase of Space Rider is a new environment that needs to be analysed and justified.
The first point will be the effect of radiations and atomic oxygen on the TPS. The ceramic materials used for the shingles and insulation layers are not sensitive to this environment and it should not be an issue.
ArianeGroup is also confident that the thermal variation between day and night will not have a significant effect as it will be very low compared to the thermal variation during re-entry .
The most critical point of orbital life for the TPS is micrometeoroids and orbital debris (MMOD) impacts.
Experiment on previous programs has shown that micrometeoroid should pierce the CMC panels without major impact neither on its thermal performance nor on its mechanical resistance. A dedicated test plan with plasma test (to simulate re-entry) on impacted material is foreseen in the next steps of the project.

3.3 Landing

A major change in the TPS panels and panels' pattern is driven by the need of integrating the landing system. Some of the panels will be mobile and will open during the last instants of the descent phase to deploy the landing gears for the horizontal landing.

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Specific design for the concerned panels is in progress. The insulation seals design will also be tuned to allow smooth opening. To reduce development costs (design, justification, tooling) the number of panels concerned by this modification had been limited.

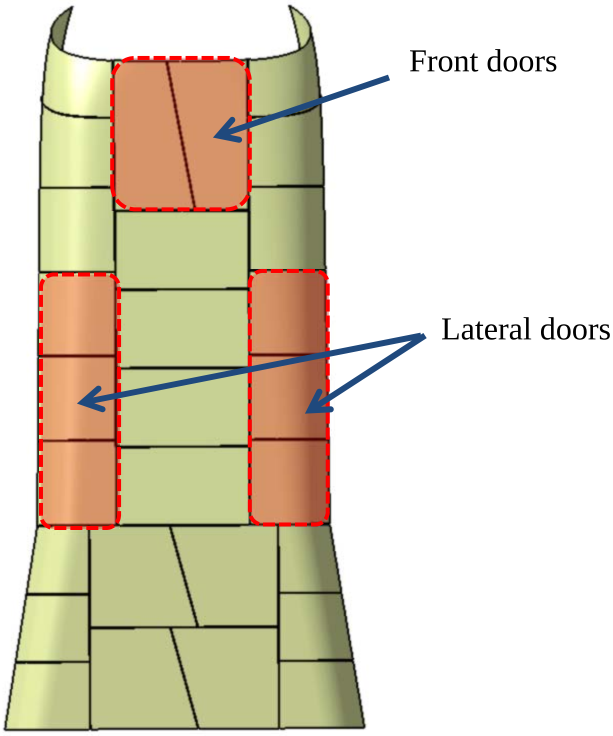

Figure 8 – Space Rider shingle pattern and modified panel for landing gears doors

3.4 Reusability

The main challenge for the Space Rider TPS will be the 6 flight reusability of the vehicle with the objective of avoiding any panel change or refurbishment between 2 flights.
The cumulated thermal effect had been tested during the CNES generic shingle program by the simulation of 11 successive re-entries through plasma torch testing on representative size CMC samples. After tests the materials presents a limited loss of mass (about 6%) and also a limited loss of mechanical behaviour (about 5% on mechanical stress resistance).
These results give confidence in the design but to reach the justification level a significant test plan should be implemented. Some thermomechanical tests of an assembly of representative panels to validate the TPS system (CMC shingle with seals, insulation layers and attachments) are foreseen.
The mechanical fatigue due to launch and re-entry phases also has to be validated by tests on coupons and representative breadboards.

3.5 Refurbishment

Anticipating the level of refurbishment needed between two flights is a challenge to. AGS proposes a preliminary inspection plan after the first flight in order to evaluate the TPS health :

- Post flight data analysis will provide data regarding the real thermal conditions of the re-entry and the potential impact on the re-usability of the TPS
- a visual inspection of the vehicle surface to check for potential MMOD impacts (or other damages)
- a more detailed inspection on critical points to verify the skin material evolution.

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In case of evidence of damage or flight parameter not covered by the justification the dismounting of panels for destructive analysis and replacement will be necessary.
The inspection of the IXV hardware after flight is proposed as a first mandatory step to support the development of this inspection logic before the first Space Rider landing

2. Conclusion

At this stage the project is in line with the objectives and a large part of the IXV TPS design will be re-used with a rigorous justification of new requirements.
The Space Rider is in a design phase with a Critical Design Review foreseen in next October and several milestones remain before the maiden flight. A very interesting and challenging part will be development and qualification tests campaign expected to be launched early 2020 to justify all these requirements.

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