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Development and flight qualification of the C–SiC thermal protection systems for the IXV☆

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The Intermediate experimental Vehicle (IXV) atmospheric re-entry demonstrator, developed within the FLPP (Future Launcher Preparatory Programme) and funded by ESA, aimed at developing a demonstration vehicle that gave Europe a unique opportunity to increase its knowledge in the field of advanced atmospheric re-entry technologies. A key technology that has been demonstrated in real conditions through the flight of this ambitious vehicle is the thermal protection system (TPS) of the Vehicle. Within this programme, HERAKLES, Safran Group, has been in charge of the TPS of the windward and nose assemblies of the vehicle, and has developed and manufactured SepcarbInox® ceramic matrix composite (CMC) protection systems that provided a high temperature resistant non ablative outer mould line (OML) for enhanced aerodynamic control. The design and flight justification of these TPS has been achieved through extensive analysis and testing:

- Mechanical, Dynamical and thermo-mechanical analysis.
- Coupons and technological tests.
- Sub-scale tests specifically made to assess the behaviour of the TPS during re-entry.
- Full scale qualification tests that addresses the flight envelope of the vehicle:
  - Sine, Random and shock tests on nose and windward.
  - Thermal test of the nose.
  - Mechanical tests of nose and windward.

  This paper describes the Flight Model TPS design, as well as the development activities, tests and results that lead to the qualification of the nose and windward TPS assemblies.

1. Introduction

IXV is an ESA programme for the acquisition of in-situ data for a lifting body vehicle during re-entry and in-flight validation of critical technologies, such as thermal protection systems (TPS). The prime contractor is Thales-Alenia Space, and the vehicle has the following main dimensions and characteristics:

- Length: 4.40 m+0.66 m (flaps).
- Width: 2.24 m.
- Height: 1.54 m.
- Mass: about 1.9 t.

HERAKLES has been in charge of the design and manufacturing of the windward assembly and nose TPS (see Fig. 1).

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The IXV mission is representative of a Low Earth Orbit return, with a Mach number of about 28 at 90–100 km altitude, and max heat flux specified at 650 kW/m^2. This led to an estimated max temperature on TPS outer skin of 1650 °C. The duration of the re-entry is 20 min, during which the acoustic load is 70 dB, and deceleration is 3 g.

2. TPS concept

The TPS concept is based on the "shingle design", which dissociates thermal and mechanical functions. A thin, heat resistant 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 Fig. 2).

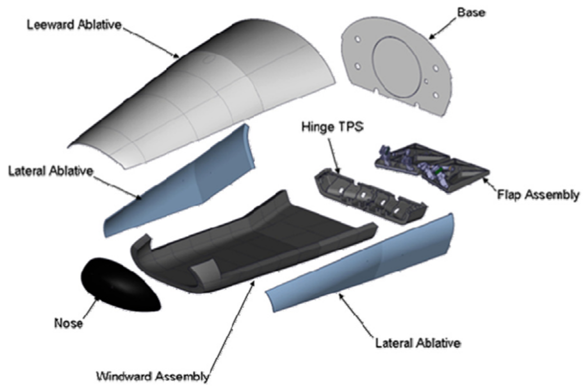

Fig. 1. IXV TPS assemblies.

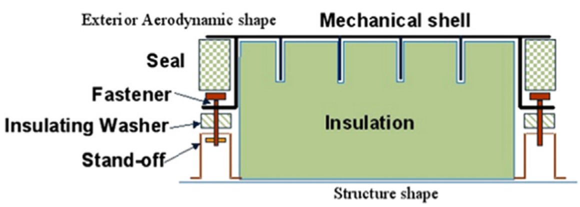

Fig. 2. TPS concept.

The 2 main advantages of this concept are that the CMC is heat resistant, and thus 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.

This concept of TPS has initially been developed by HERAKLES, Safran Group, for the Hermès European shuttle programme. Through the CNES-funded "Generic Shingle" programme, then the ESA-funded "Future Launcher Preparatory Programme" [3,4], numerous tests have been performed prior to the start of the IXV detailed design phase (c.f. Fig. 3).

The result of these tests confirmed the high potential of the CMC TPS technology for an application on a re-entry mission, through the following basic verifications:

- thermal protection performance (maximum temperature of the underneath structure),
- resistance to launch environment (sine, random and acoustic loads, venting),
- resistance to re-entry environment (high convection heat flux due to air plasma, re-pressurisation),
- manufacturing feasibility for C–SiC large flat parts (up to 800 mm long).

All these preliminary activities had been performed with a set of specifications that were very close to the specifications of the early phases of the IXV, which provided confidence in the applicability of the technology for the thermal protection system of the vehicle.

3. IXV TPS description

TPS of the IXV are made of three main components: CMC skins, insulation material and attachment system. The outer skin of the TPS is made of Carbon–Silicium Carbide (C–SiC) material. There are 30 panels for the windward (see Fig. 4), made of a thin outer layer with integrated woven 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.

Each panel, and the nose, is equipped with insulating materials. Different materials are used, selected for their

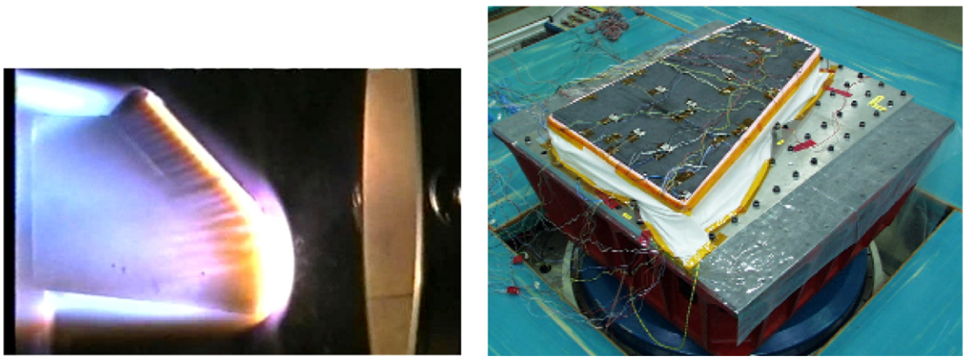

Fig. 3. Plasma Wind Tunnel (PWT) test in Scirocco facility (left) and launch-representative dynamic test (right).