European Directions for Hypersonic Thermal Protection Systems and Hot Structures

31st Annual Conference on Composites Materials and Structures
Daytona Beach, FL
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Agenda

- **Background**
  - Comments on prior ESA workshop
  - X-38
  - Hopper
- **Flight Vehicle Based Technology Development**
  - IXV (ESA)
  - EXPERT (ESA)
  - USV (Italy)
  - SHEFEX (Germany)
  - SHyFE (UK)
  - LEA (France)
  - Foton (Russia)
- **Non-Vehicle Specific Technology**
- **Concluding Remarks**

European TPS and Hot Structures Research and Development

- **TPS and hot structures research and development critical for future space vehicles**
- **Developing next generation TPS and hot structures technology (not Space Shuttle derived technology)**
- **Long-term funding based on technology needs**
- **Wide industry support and commitment to X-38 program**
- **Test facilities developed for TPS and hot structures development**
  - Thermal/structural test chamber
  - Arc-jet tunnels developed in recent years
- **Technology development has broad base**
  - Fabrication
  - Testing
  - Large components
  - Fasteners
  - Bearings
  - Oxidation protection
  - Damage repair
  - Life cycle

Wayne Sawyer comments from previous ESA TPS & Hot Structures Workshop

European TPS and Hot Structures Research and Development

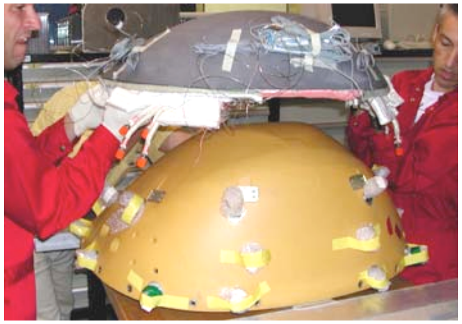
- **Proposing numerous experimental launch vehicles dedicated to or with TPS and hot structures research of prime consideration**

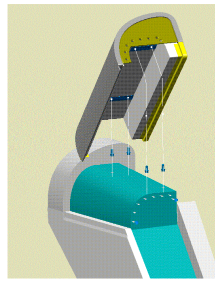
- **Committing significant resources to the development of TPS and hot structures for future space vehicles**
  - $20 million spent on C/SiC body flaps for X-38, $50M on X-38 technology by Germany
  - Many companies involved (committing resources) in developing C/SiC hot structure for X-38
  - Large thermal/structural test chamber developed specifically for verification of X-38 hot structure

- **European TPS & Hot Structures Emphasis**
  - Developing ceramic matrix composite and metallic TPS with fibrous insulation
    - Waterproofing not required
    - Larger unit size (reduce part count)
    - More durable (reduced inspection and repairs)
  - Developing ceramic matrix composite and metallic hot structure
  - No ceramic tile development
  - Limited development with blanket insulation

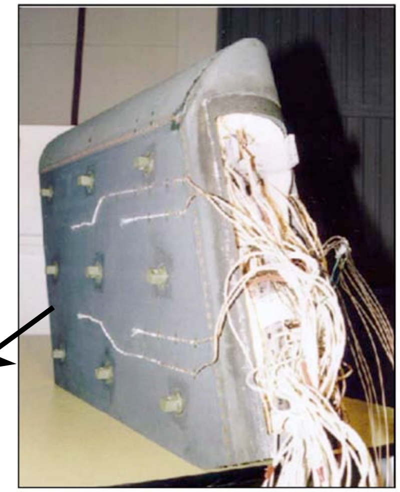
Wayne Sawyer comments from previous ESA TPS & Hot Structures Workshop

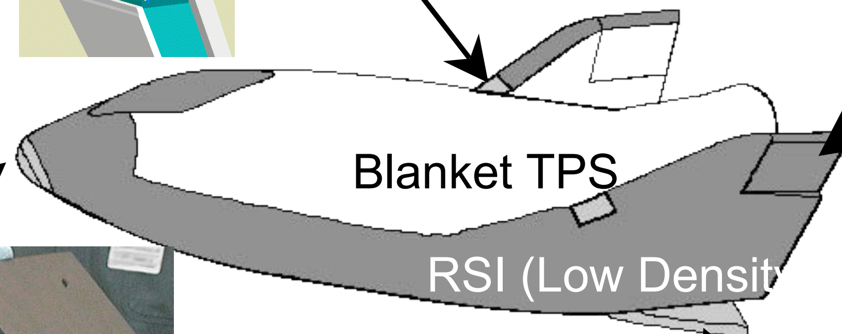
X-38 Hot Structures





- **C/SiC leading edge**
  (flight experiment, 2000°F)
  - MT Aerospace (Germany)





- **Metallic rudder**
  (Dutch Space)

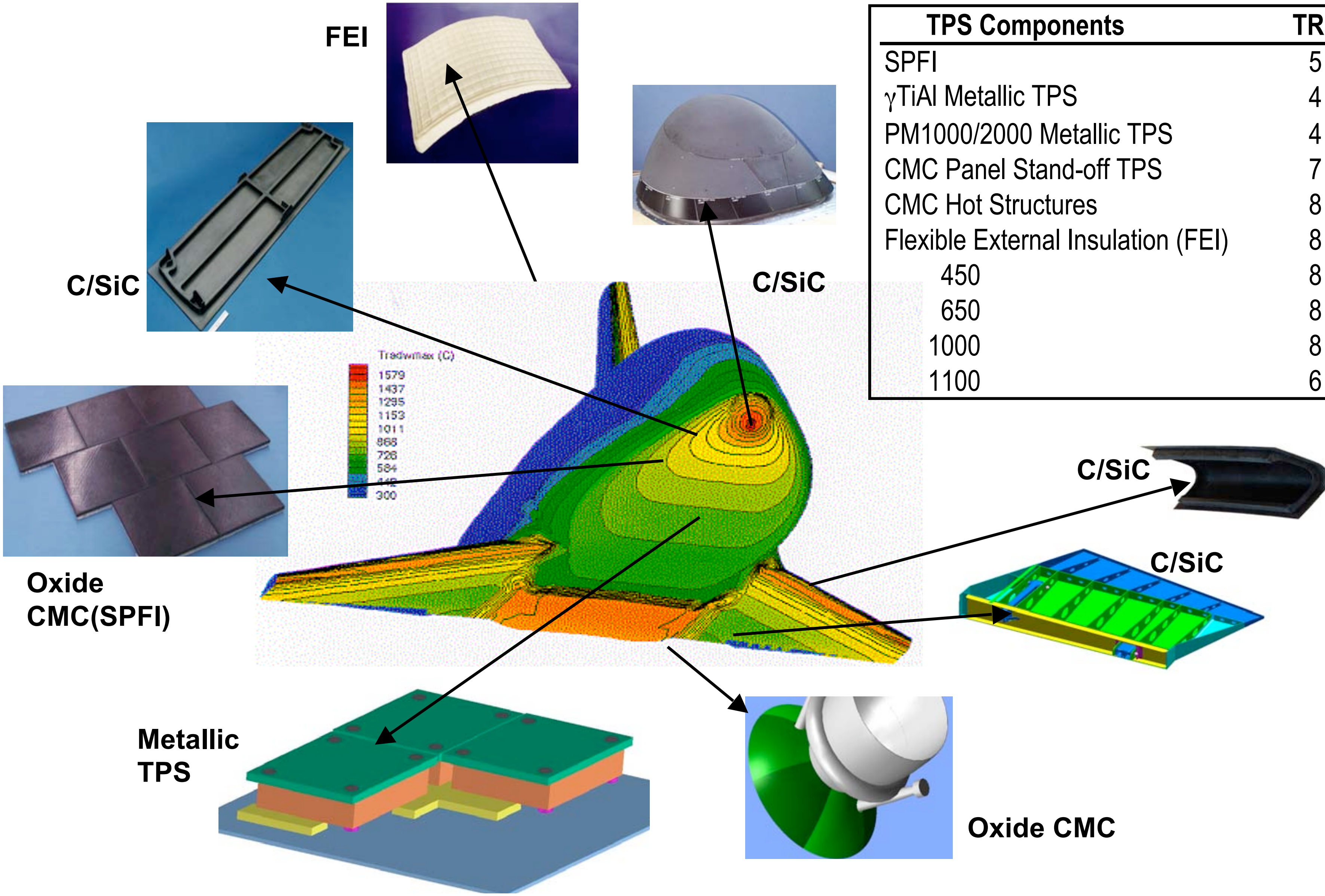
- **C/SiC nosecap & skirts, T_{max} ~ 3200°F**
  - Nosecap provided by DLR (Germany) (C-C, liquid Si infiltration fill cracks, final CVI SiC coating)
  - Nose skirts (2) provided by DASA (Germany)
  - Chin panel provided by MT Aerospace
  - Nose assembly has undergone full qualification (qual units)
    - Vibration
    - Thermal (radiant)
    - Mechanical

- **C/SiC bodyflaps**
  - MT Aerospace

~$20M

EADS TPS & Hot Structures Hardware for Hopper

TPS Components	TRL
SPFI	5
γTiAl Metallic TPS	4
PM1000/2000 Metallic TPS	4
CMC Panel Stand-off TPS	7
CMC Hot Structures	8
Flexible External Insulation (FEI)	8
450	8
650	8
1000	8
1100	6



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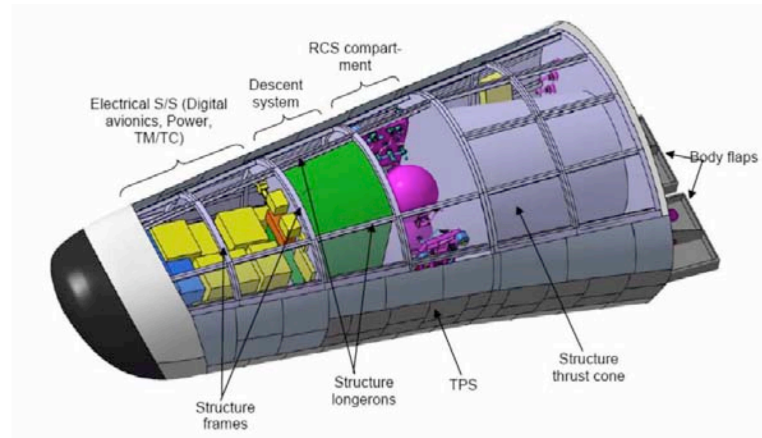
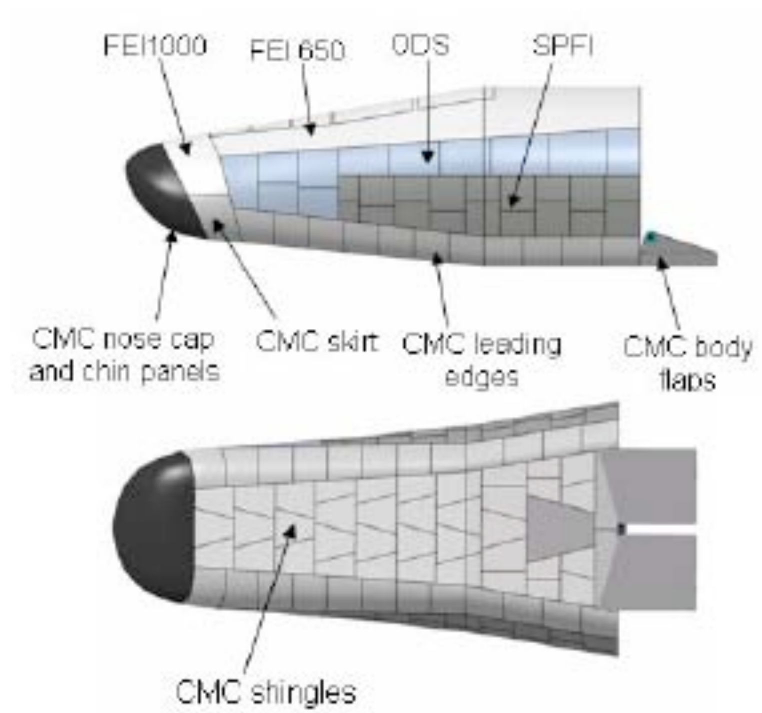
Intermediate Experimental Vehicle (IXV)

- **Part of ESA FLPP**
  - Run by NGL Prime, joint venture of Astrium (F, D) and Finmeccanica (I)
- **PDR end of 2007, first flight end of 2010**
- **Objectives**
  - System design experience for lifting reentry vehicles
  - Flight test in representative environments TPS & Hot Structures for Next Generation Launchers (NGL)
  - ATD data to validate tunnels and CFD
- **Build on X-38 nose and body flap experience**
- **Both experimental and functional**
- **Leeward and base side utilizes Flexible External Insulation (FEI)**
  - FEI 1000, 650,450
  - ODS metallic TPS
- **Windward side**
  - C/SiC shingles of different size
  - C/SiC leading edges, either fixed hot structure or shingle
  - Surface Protected Flexible Insulation (SPFI)





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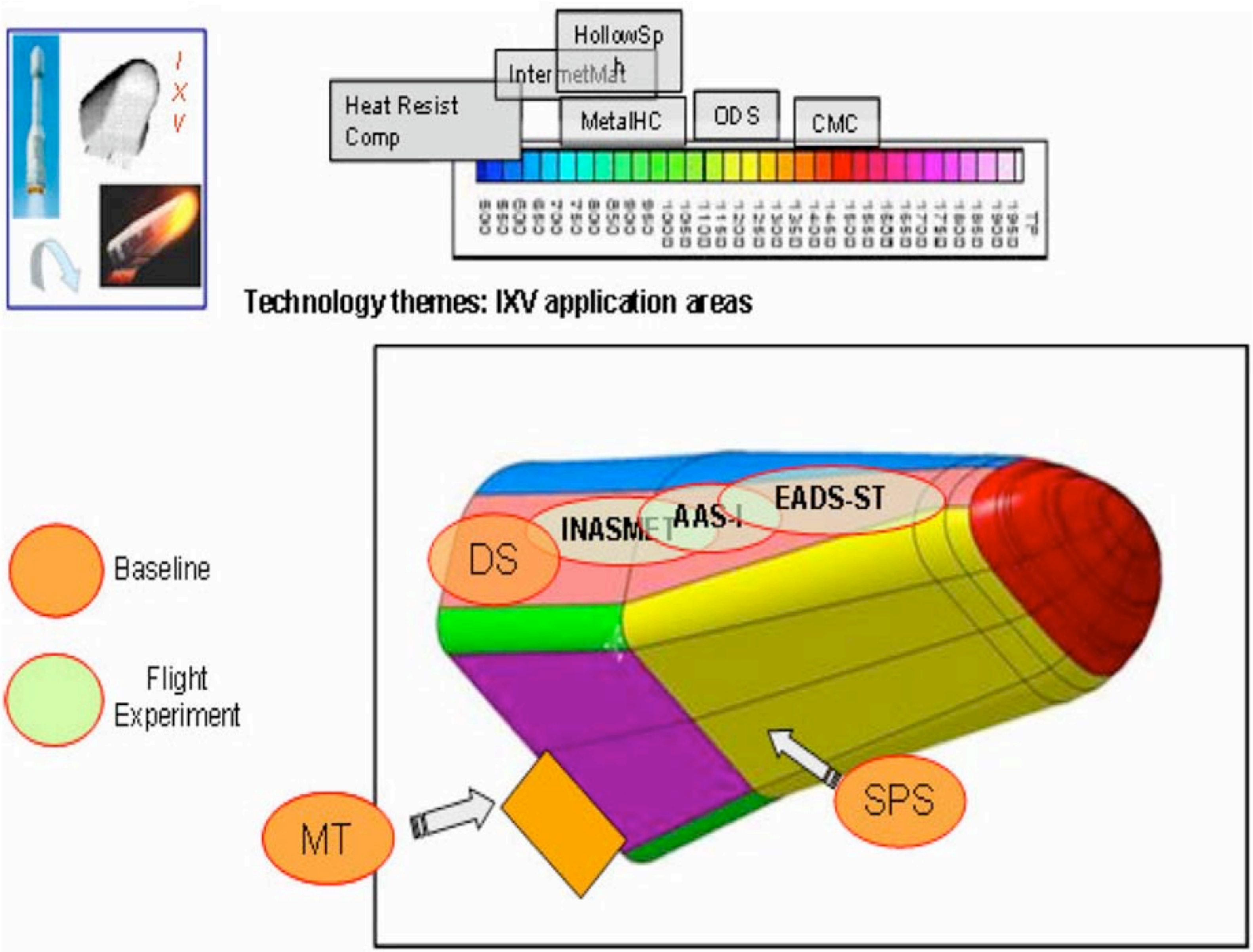
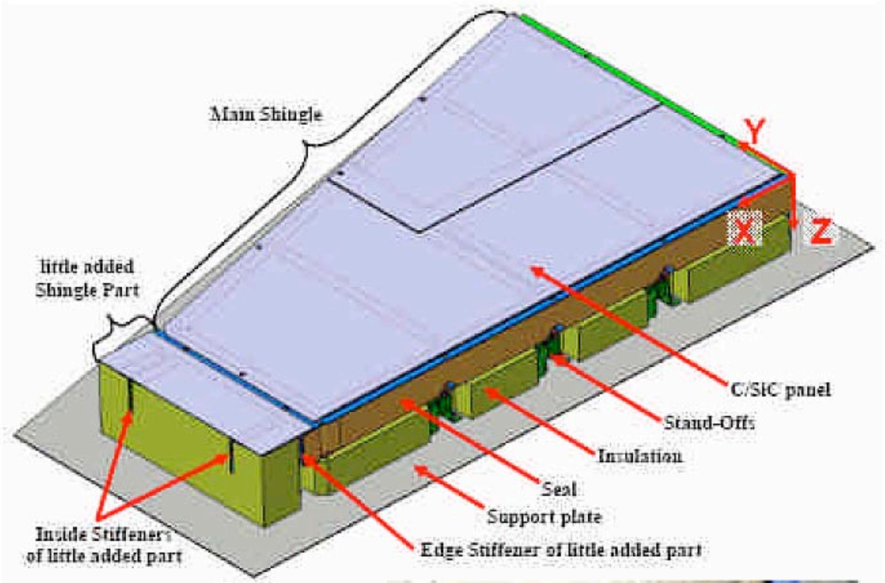
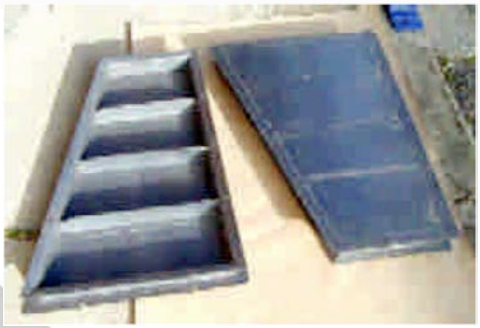
TPS & Hot Structures Technologies on the IXV

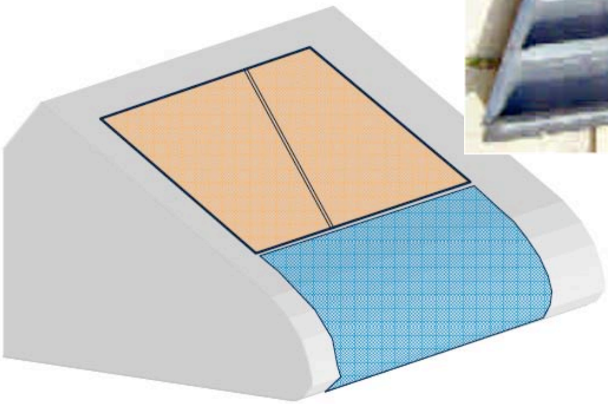


IXV C/SiC Hot Windward Surface TPS (Snecma)

- **TRL 4-5, baseline vehicle technology**
- **Development tasks**
  - Base material characterization - long duration PWT tests
  - Sub-assembly test (lift-off, flight, re-entry environment)
    - **Structural integrity**
      - Sine and random test of hard mounted TPS
      - 2 shingle, seals, interfaces, etc.
    - **Structure characterization**
      - Modal survey for design assumption correlation purposes
  - Test demonstrator in representative thermal and pressure environment
    - **CMC TPS shingle sub-assembly**
    - **Scirocco PWT 1000 sec**
      - Structural integrity in worst thermal environment
      - Insulation performance for support structure
      - Seal integrity and performance
      - Attachment interfaces insulation and stress relief functions
      - Degradation characterization
      - Analysis models verification

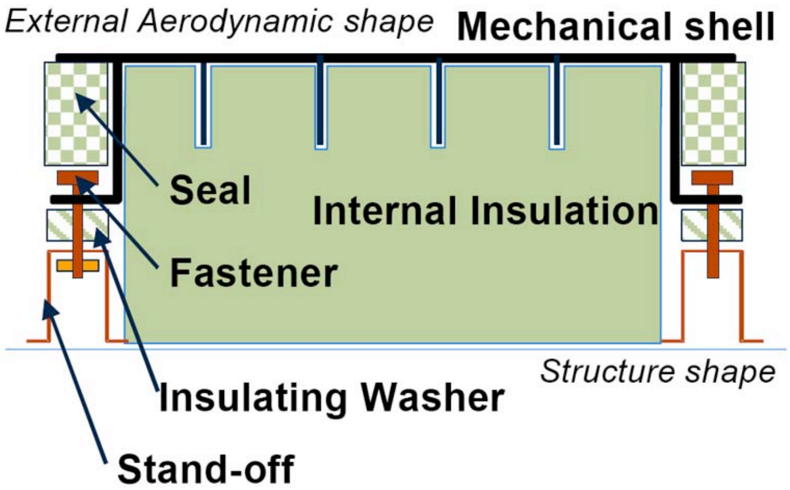


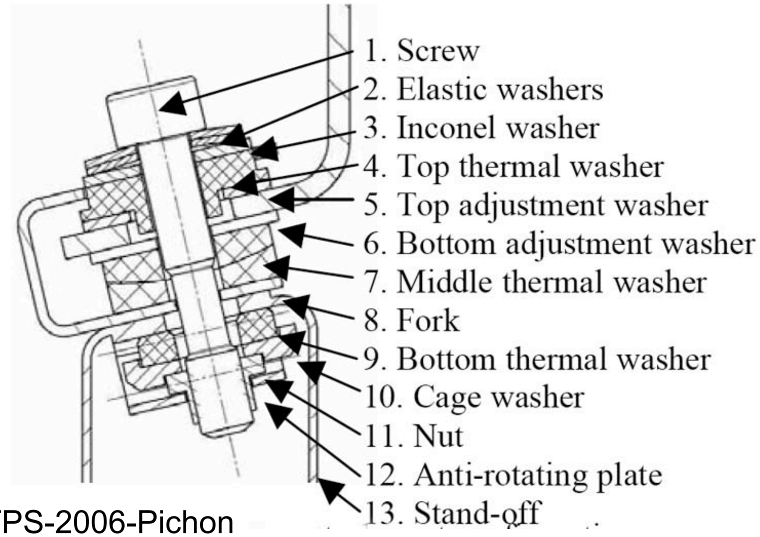




IXV CMC Shingle TPS (Snecma)

- **Decouple the thermal (insulation) and mechanical functions**
- **Design**
  - External C/SiC thermal shield panel
  - Outer oxidation protection system
  - Internal ceramic felt insulation
  - Static high temperature seals
  - Special attachment fixtures combining isolation and thermal stress relief
- **Tasks**
  - Design of panel and attachments
  - Analytical validation of design
  - Manufacturing of complete large shingle
  - Mechanical test of C/SiC panel
  - Testing likely done by now
    - **Dynamic**
    - **Acoustic**
    - **Thermal**
    - **Thermo-mechanical**





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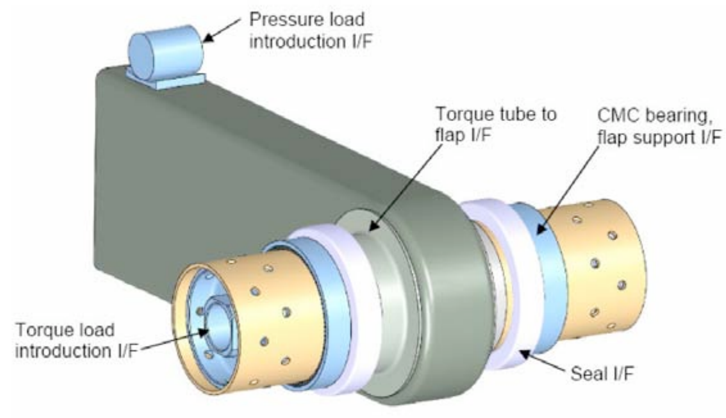
IXV C/SiC Control Surfaces (MT Aerospace)

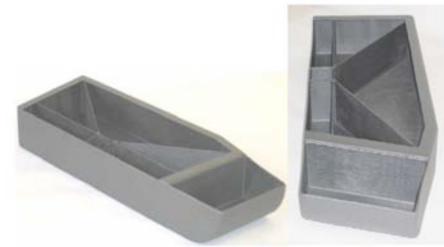
- Includes hot interface components (bearing, seals, joints)
- X-38 based design and manufacturing
- TRL 4-5, baseline vehicle technology

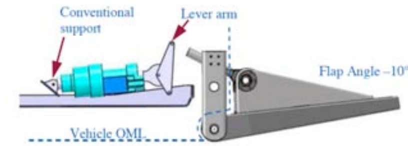


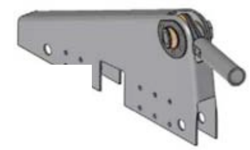
- Torque driven body flap
  - Prototype roller bearing sub-assemblies
  - Dynamic seals
  - Driving torque load introduction interface
  - Tube to flap frame joint (validating a “one shot” production process of complex composite parts)
- Development tasks
  - Hot verification of structural strength of joint (in-situ joining manufacturing technology) between torque tube and flap frame
  - Thermo-mechanical cycling of body flap demo with IXV T, P profiles
    - **Structural integrity of demo in worst thermal mechanical conditions (50 cycles)**
    - **Dynamic hot seal performance**
    - **Hybrid (metal & CMC) roller bearings functionality, integrity, and attitude maintenance**

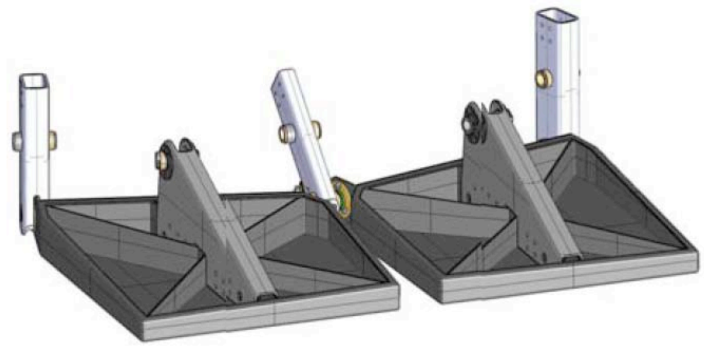
Pre-X CMC Flap Development (MT Aerospace)

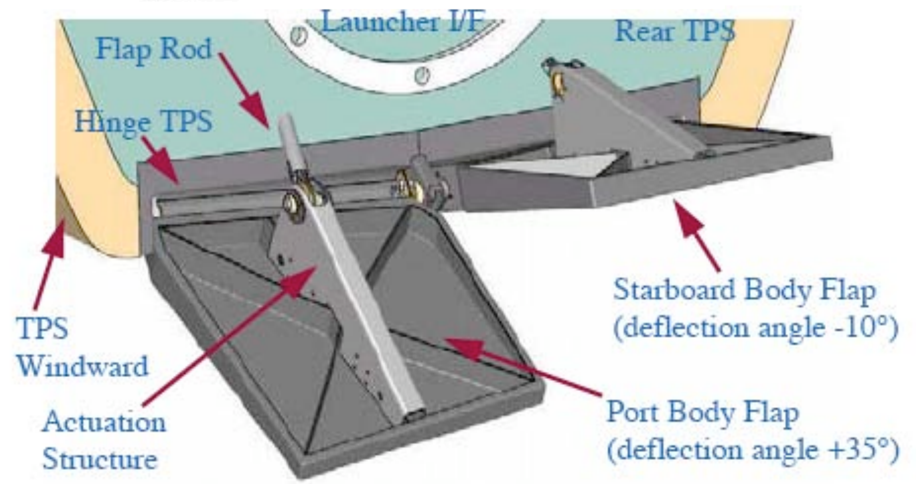
- **C/SiC design**
- **Mass is 23.63 kg (7% over goal)**
- **Flap structure**
  - Cross-wise stiffeners yields most efficient torsion stiffness (1st eigenmode)
  - 2.5 - 5 mm thick
  - Open box vs closed box for X-38 design
  - Evaluated both 1 and 2 piece
- **Ceramic bearings**
- **Attachment at hinge line**
  - Rectangular C/SiC tubes
- **Actuation mechanism**
  - C/SiC rod vs arc used on X-38
- **Hot dynamic seals**
  - Nextel/saffil
- **CMC fasteners**
  - Fewer than X-38 due to no box cover

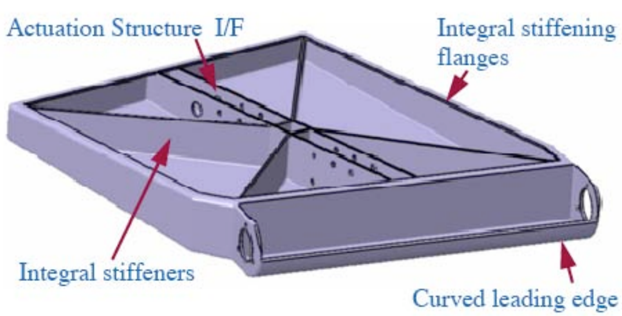




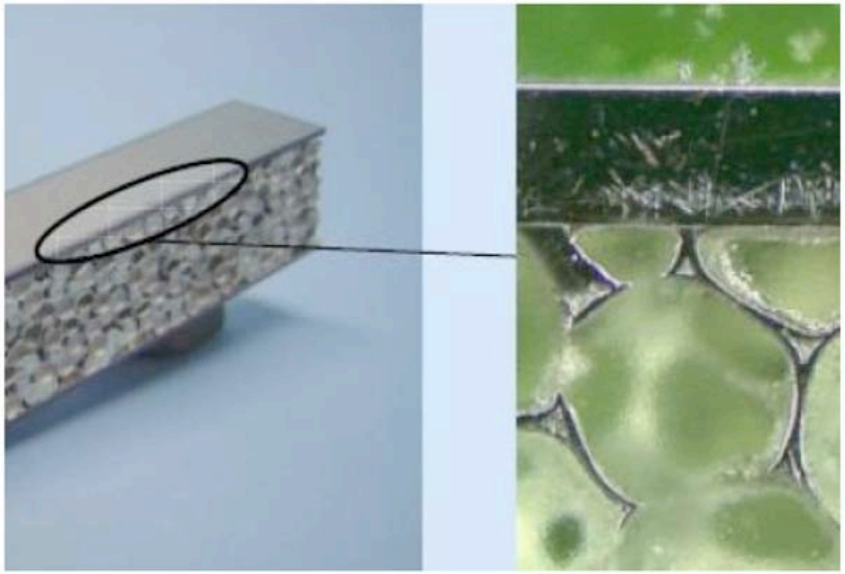




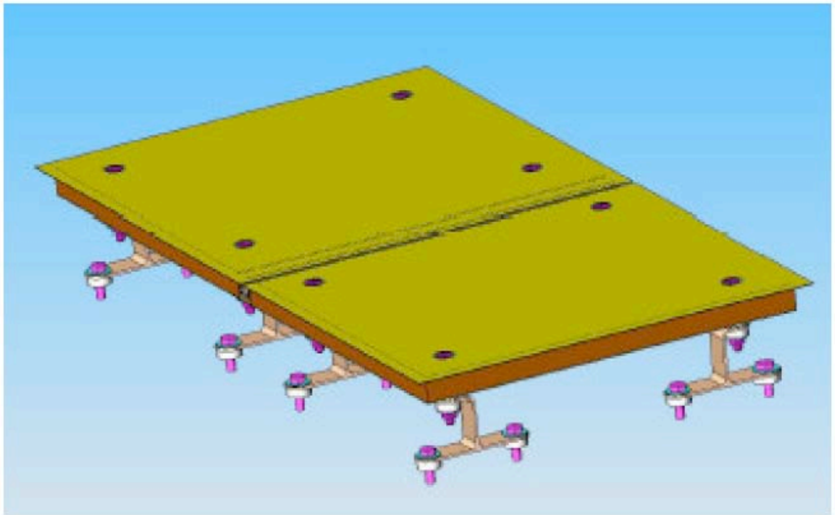




IXV Metallic Sandwich TPS

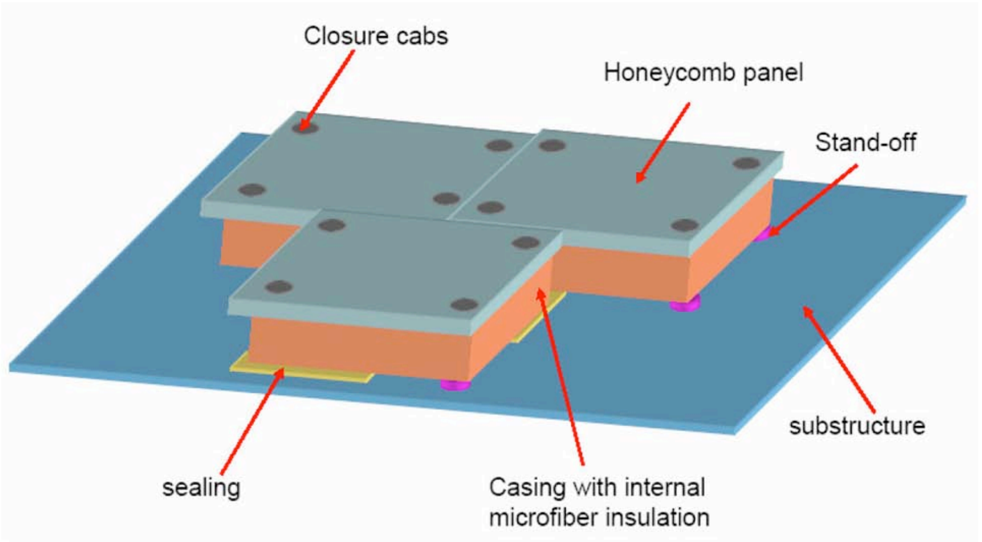


- **Metallic sandwich TPS**
  - Multiple cycles to 900°C
  - Core is stainless steel hollow spheres (Alcatel Alenia Space (I) and Plansee (A))
  - HollowMet core (ODS hollow sphere)
- **TRL 2-4**
- **Passenger experiment on IXV**
- **Development tasks**
  - Material development and characterization for core
    - **Minimize mass for given thermal mechanical load**
  - Thermal cycling of subassembly of ≥ 2 tiles, including interfaces, seals, and insulation
  - Hypervelocity impacts testing (exploit energy absorption of material)



IXV Metallic Honeycomb TPS

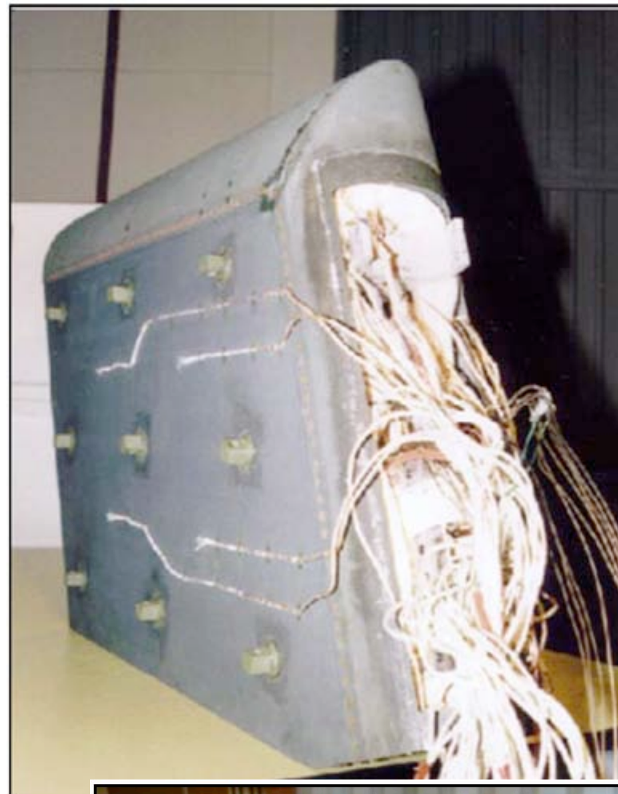
- **TRL 2-4**
- **TIMETAL 1000 for use to 850°C (Astrium)**
  - Orthorhombic TiAl (Ti_2AlNb) or TiAl reinforced TiB
  - Passenger experiment on IXV
- **ODS Superalloys up to 1250°C (Dutch Space)**
  - IN 617
  - Baseline vehicle technology
  - Windward aft or leeward aft
  - Development tasks
    - **Design trades on seals, insulation, and interfaces to cold structure**
    - **Manufacture and test of selected design**
    - **Thermal cycling under IXV thermal and pressure profiles (2 TPS tiles)**
    - **Foils production**
    - **Core manufacturing**
    - **External sheet to core brazing**



TIMETAL panels

IXV Metallic TPS & Hot Structures (Dutch Space)

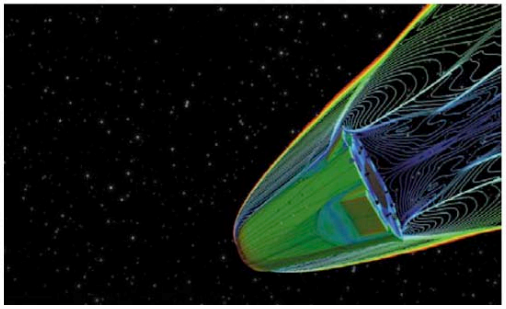
- **AEOLUS team since 1993, lead by Dutch Space**
- **X-38 hot rudder**
  - Fab and tested a PM-1000 rudder to 1200°C (1 yr)
  - Requirements changed
  - Qualified Ti/CMC rudder (1 yr)
- **Sandwich panel**
  - PM-1000 facesheets
  - PM-2000 core
  - Vacuum brazing
  - 47 ascent/descent cycles - good condition
  - Low and high speed (hail, 208 m/sec) impact test performed - good performance
- **New design (post X-38) demonstrated**
  - Thermo-mechanical tests performed and compared well to analysis
  - Sandwich panels with inserts and edge members
  - Corrugated webs with stress/strain reducing clips
- **Extensive materials database developed**
- **Manufacturing development performed**



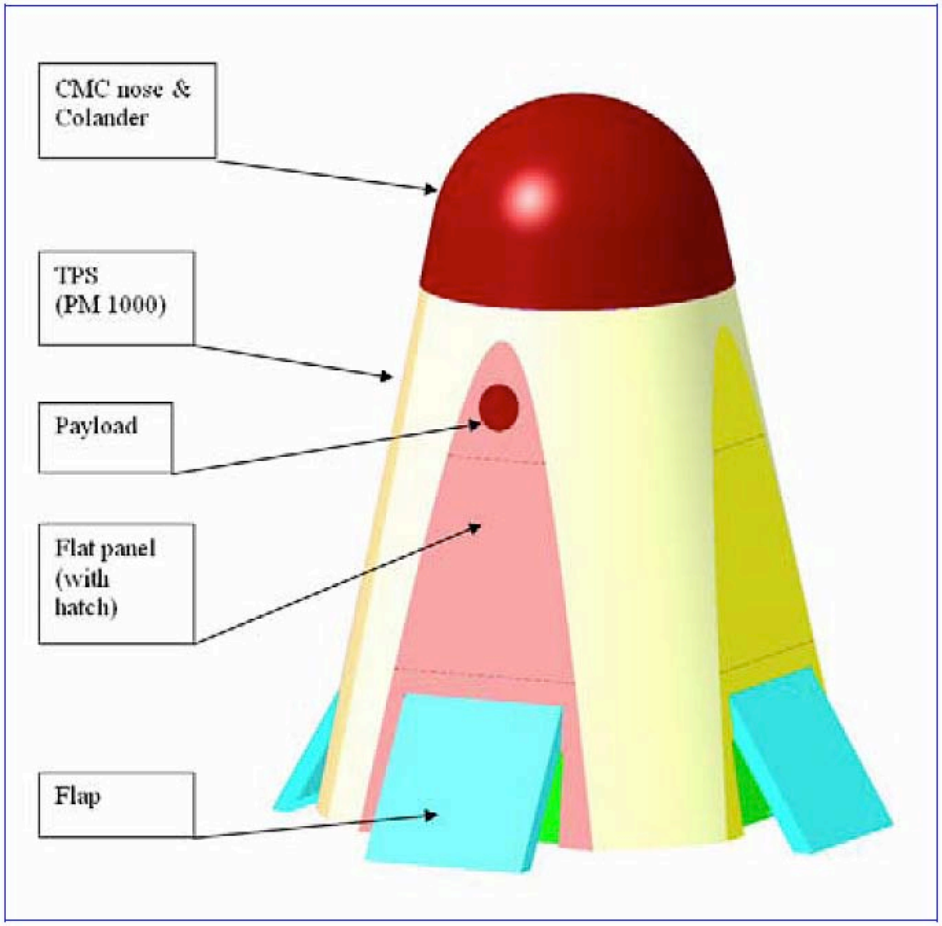
ESA-TPS-2006-Mooij

European eXPErimental Re-entry Testbed (EXPERT) Flight Experiment TPS (ESA)

Configuration: Blunt cone configuration with a pyramidal shape (called KHEOPS) having four flat surfaces, each with a fixed flap (two fixed flap settings).

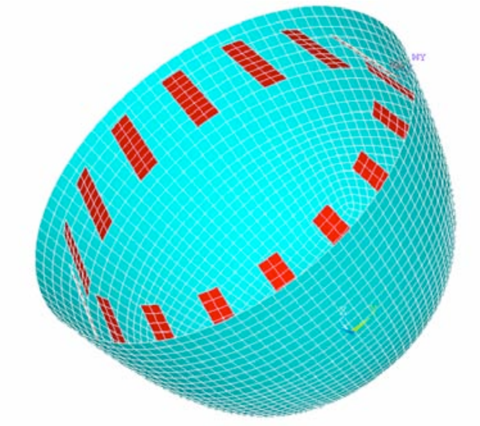


- Relatively large nose radius (R_N < 0.4 m, L = 1.7 m, d = 1.3 m) to minimize stagnation heating rates and ablation pollution
- 5 km/sec, entry path angle -5.5°, 3° AoA
- Curved corner TPS (4)
- Flaps---study complex physics and X-38 issues; protected with TPS, instrumented on both sides
- Flat panels, including flap box and flaps (1050 mm^2, 1100 mm high)



EXPERT C/SiC Nose Cap (DLR)

- ♦ **Based on X-38 experience (led by DLR Stuttgart)**
- ♦ **Internal flexible insulation below surface**
- ♦ **q_{max} = 1,600 kW/m^2**
- ♦ **Material choice C/C-SiC**
  - Avoided ablator
    - **Geometrical stability**
    - **Chemical pollution of flowfield**
- ♦ **Load transfer from nose to vehicle cold structure**
  - Elevated temperatures
  - Thermal expansion of nose
  - Thin metallic brackets bolted to nose and to cold structure
    - **Less susceptible to side loads than X-38 based double bolt-joint design**
    - **Low complexity and cost**
- ♦ **Active oxidation in dissociated environments is accompanied by a sudden temperature increase of up to 500K.**
- ♦ **Recombination coefficients determined for C/SiC and PM 1000 in O_2 and N_2**



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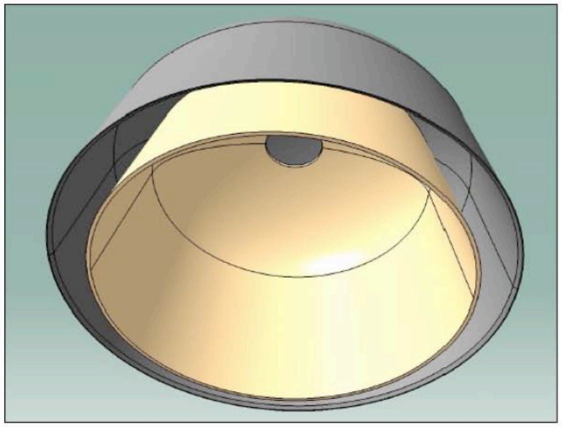
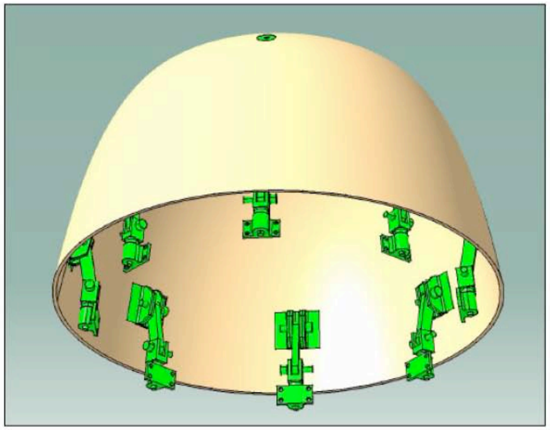
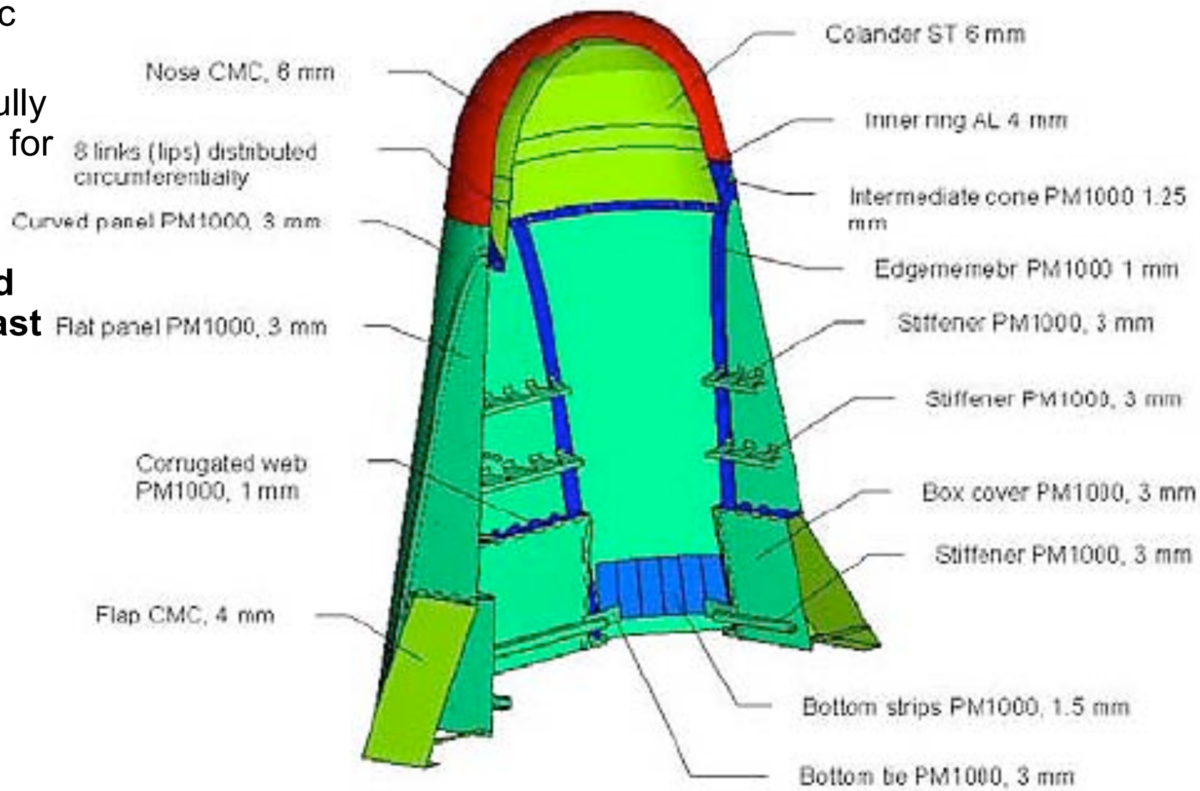




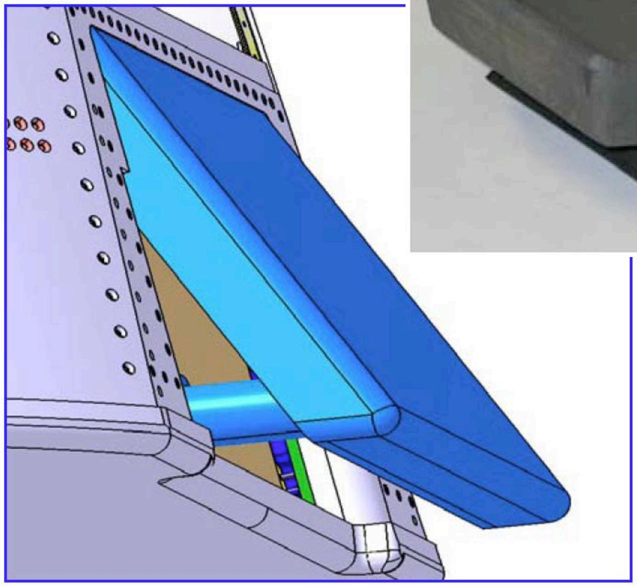
EXPERT Metallic TPS

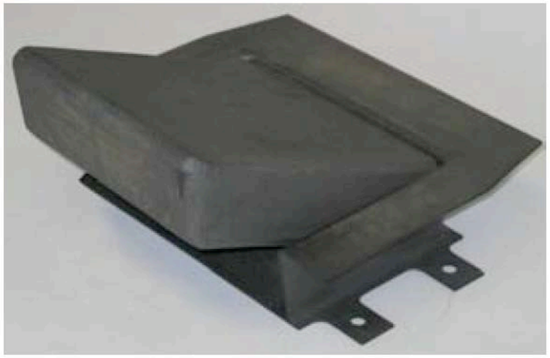
- **ODS PM 1000**
- **q_{max} = 225 kW/m²**
  - CFD assumed partially catalytic CMC and PM 1000
  - Nose non-catalytic, PM 1000 fully catalytic. Thus 1.2 factor used for conservatism
- **Extensive FEA performed**
- **Mechanical stiffness to withstand re-entry dynamic pressure and fast depressurization during ascent**
- **Internal flexible insulation below surface**
- **Nose attachment to vehicle and metallic TPS**
  - 4 mm step at RT, flush at max temperature
  - Seal designed to seal both hot and cold
  - Used inverted cone which is pulled upwards by expanding metallic TPS and counteracts the downward movement due to drag
  - Inverted cone designed to follow the deformation (~2%) of the PM 1000 metallic TPS

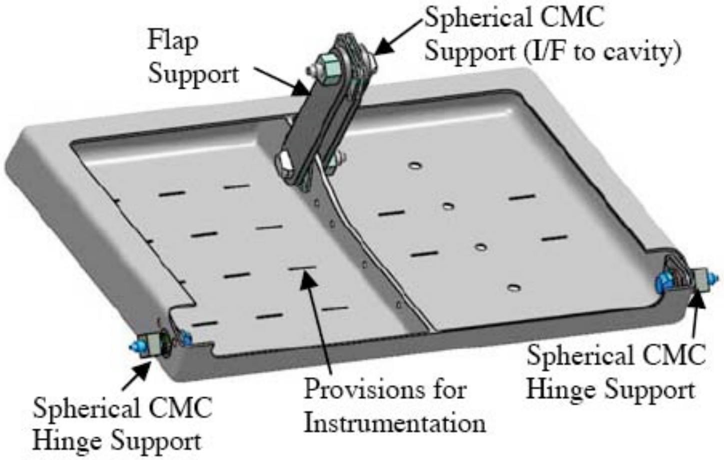


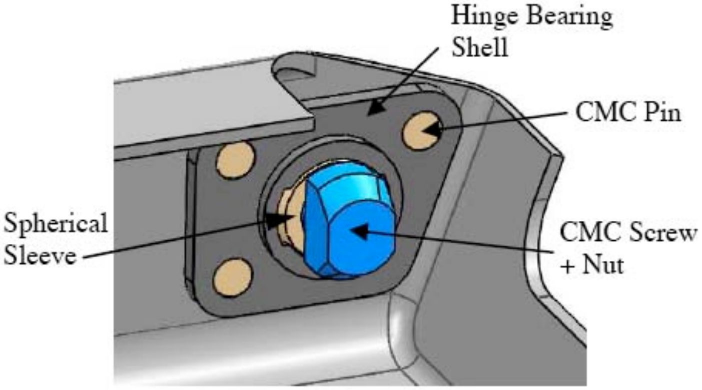
EXPERT CMC Open Flaps (MT Aerospace)

- Fixed at 20° deflection
- Open flap, 396 x 315 x 50 mm
- Two spherical supports at the hinge line
- Static hinge line seal
- Flap support connected to flap main body and PM 1000 cavity via spherical CMC bearings
- All joints CMC to eliminate CTE problems
- Flap box is designed as heat sink since flap is much hotter than metallic TPS capability
- Bearing shells fixed by CMC pins to flap main body
- Hinge seal fibrous saffil core wrapped in 1 layer Nextel clamped between flap leading edge and cavity







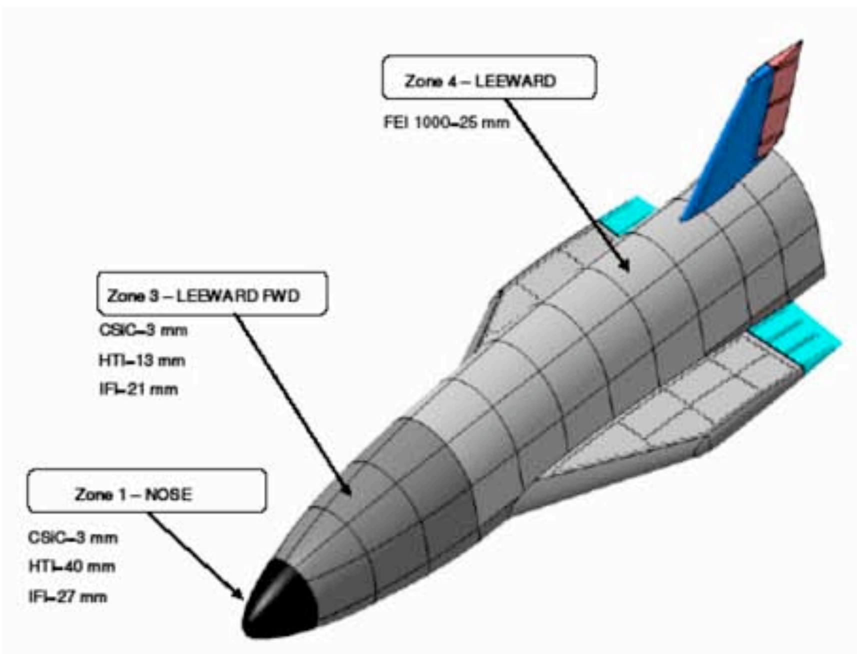


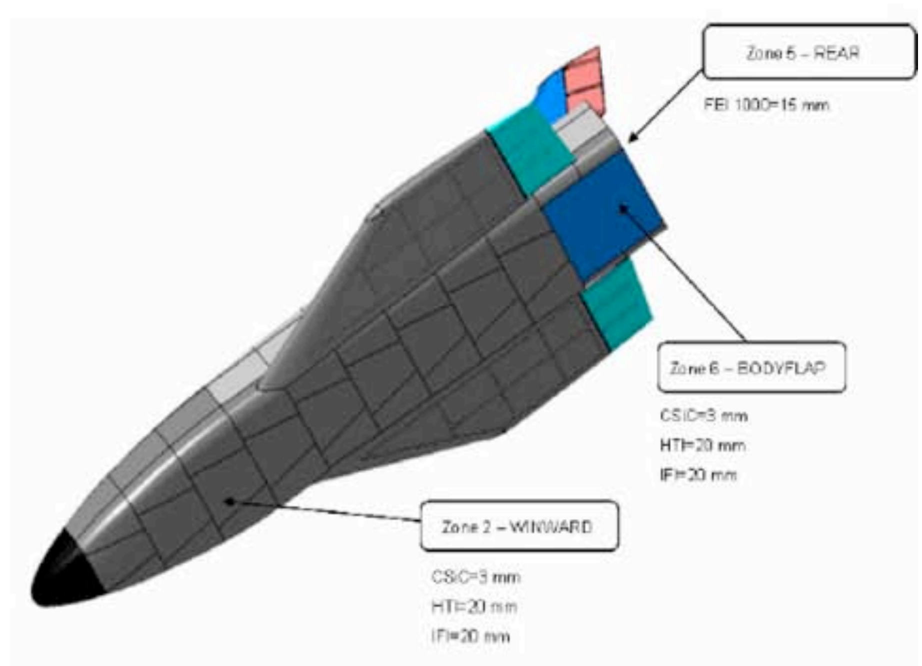
Unmanned Space Vehicle (USV)

- ♦ **Italian Space Agency / CIRA**

- ♦ **Technology development**
  - Sharp hot structures
    - **Wing leading edges**
    - **Nose cap**

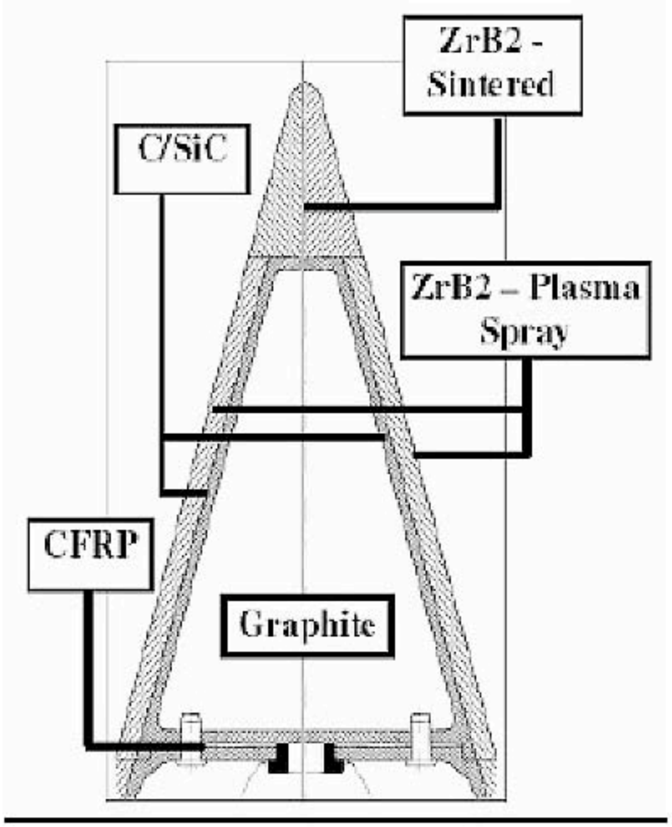
- ♦ **Orbital test bed: Flying Test Bed - X (FTB-X)**
  - Entry from LEO at 200 km
  - < 20° AoA
  - < 20 min entry





USV Ultra High Temperature Ceramics (UHTC) Nose

- **Nose design**
  - Bulk graphite core
  - Truncated conical C/SiC frame from PIP (Fabbricazioni Nucleari)
  - ZrB2-SiC coating on C/SiC frame by plasma spray (Centro Svilippo Materiali)
  - UHTC conical tip from hot pressing (National Research Council Institute for Ceramic Materials)
- **UHTC primary focus area**
  - Core/shell configuration
    - **ZrB2 core**
    - **(Zr,Hf)B2 shell**
  - Electrical Discharge Machining (EDM), and its effect on the surface
    - **Cu, Zn contamination**
    - **Decreased flexure strength**
  - Mechanical assembly
    - **Coupling pin (UHTC material to reduce thermal stress)**
    - **Contact pressure not important**
    - **Compressive stresses key**



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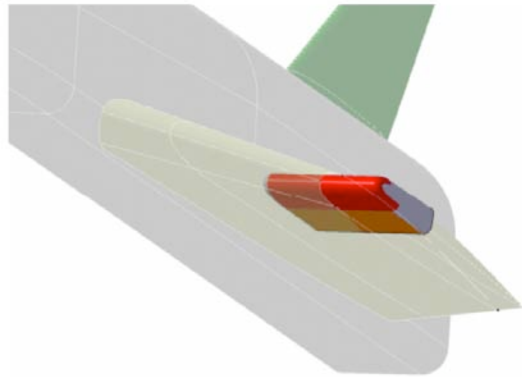
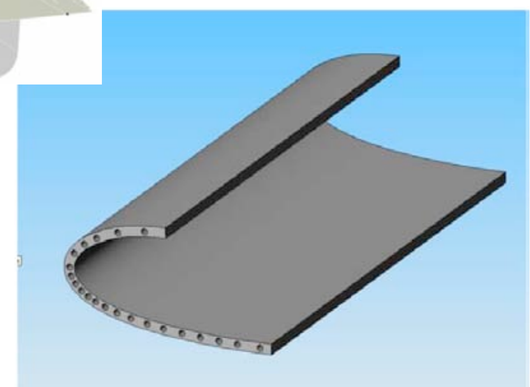
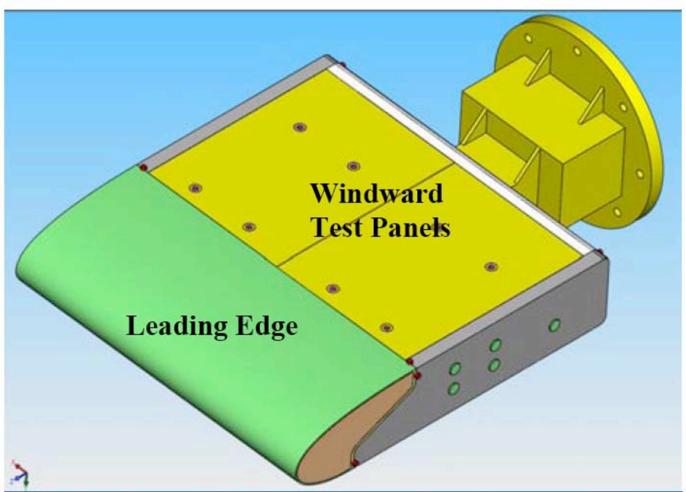
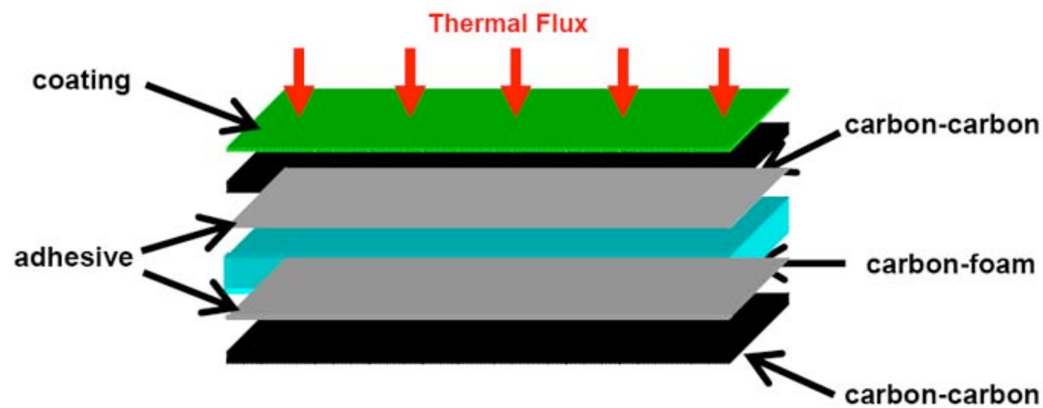
USV Wing Leading Edge (Italy)

- ♦ **Advanced Structural Assembly (ASA) program funded by ASI**
- ♦ **Wing test article for PWT test**
  - Leading edge (interchangeable options)
    - **Actively cooled: Inconel**
    - **UHTC**
  - Hybrid sandwich panel up to 2000°C (windward surface)
    - **C/C facesheets**
    - **C foam core - evaluating both co-processing and secondary bonding**
  - Leeward surface MMC (CSM)
    - **Ni sheets and SiC/Al_2O_3 fibers**









ESA-TPS-2006-Fossati-1

USV UHTC's

♦ **Multiple fabrication routes studied**

- Sintering aids
- Reactive hot pressing starting from solid precursors
- Spark plasma sintering for densification
- Introduction of second phases (SiC and $MoSi_2$) to inprove oxidation resistance and mechanical properties

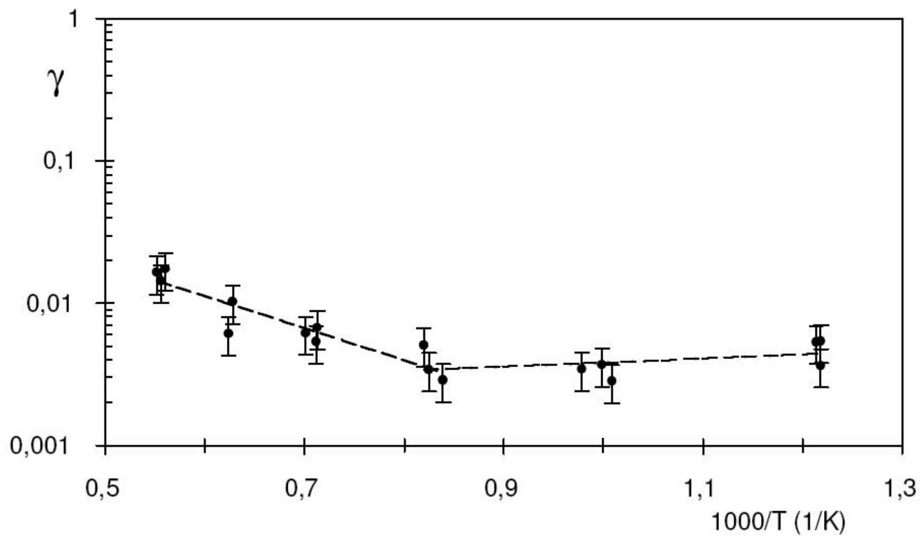
♦ **Complex shaped components via Electrical Discharge Machining**

- Compared diamond tool machining vs EDM on ZrB2-SiC

ESA-TPS-2006-Bellosi

USV UHTC Emissivity and Catalycity

- **Compositions**
  - A: ZrB2 + SiC + sintering aid ($MoSi_2$)
  - B: ZrB2 + HfB2 + SiC + sintering aid
- **Total hemispherical emissivity 10^{-3} and 200 Pa**
  - A: large difference due to pressure. 200 Pa higher ε due to oxide layer
  - B: small difference due to pressure
- **Catalycity**
  - Just composition A so far



Total hemispherical ε,
Composition A

200 Pa

T (K)	ε∩ (T)
1037	0.77
1169	0.71
1250	0.72
1319	0.73
1485	0.75
1681	0.72

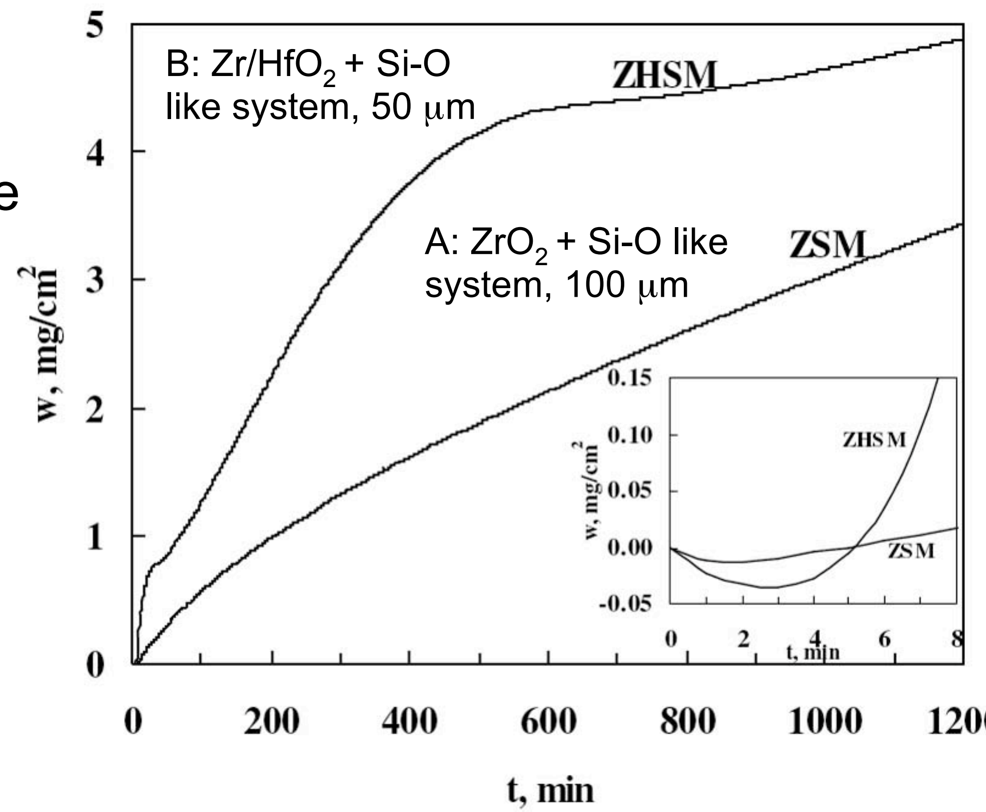
10^{-3} Pa

T (K)	ε∩ (T)
1100	0.60
1416	0.55
1556	0.61

ESA-TPS-2006-Scattela
IAC-06-C2.4.04

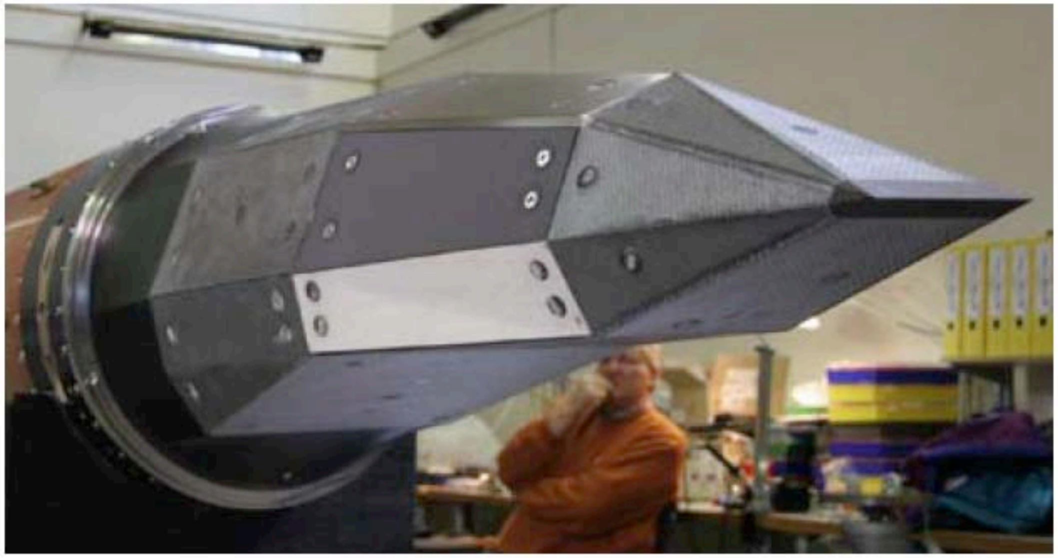
USV UHTC Oxidation

- **1200 min**
- **Dry, flowing air**
- **1450°C**
- **Mass from TGA**
- **XRD & SEM**
  - Presence of ZrO_2 and Zr/HfO_2
  - External glassy layer (Si-O-like system)
    - **100 μm for A**
    - **50 μm for B**



Sharp Edge Flight Experiment (SHEFEX)

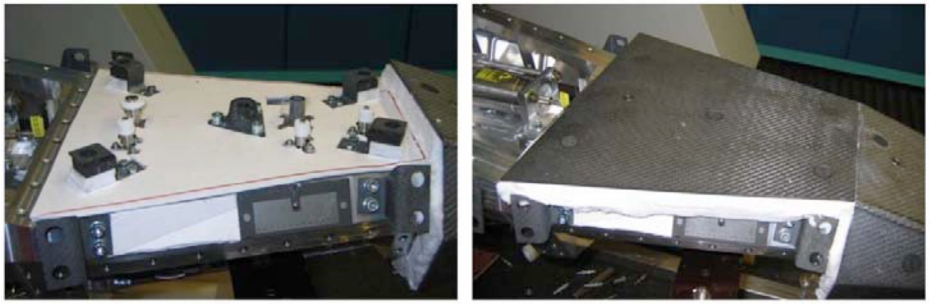
- ♦ **Funded by DLR**
- ♦ **Objectives**
  - Evaluate performance of multi-facetted leading edges
  - Compare numerical data with flight results
- ♦ **Flight Oct 27, 2006**
  - Mach 7 between 90-20 km
  - 300 km apogee



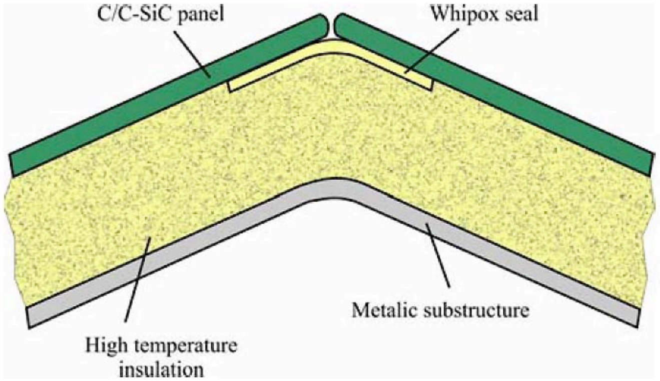
AIAA-2003-7030
AIAA-2006-7926
AIAA-2006-8071
AIAA-2006-7921
AIAA-2006-8027

SHEFEX (DLR)

- **TPS, hot structures experiment, Oct. 2005 flight**
  - Apogee 211 km
  - 550 sec
- **~3 ft long, 1.5 ft diameter**
- **Test flat, facetted, panels**
- **Seals and attachments included in test**
- **Primarily CMC's with some metallic TPS**

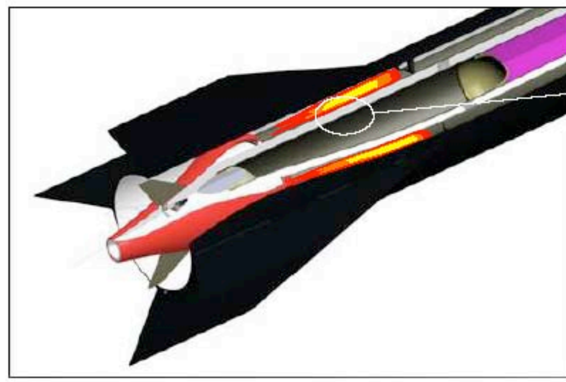


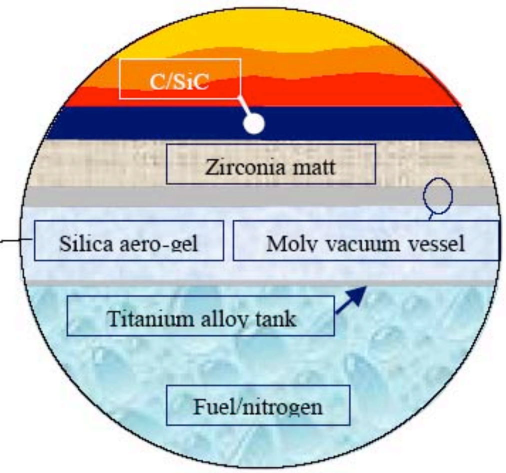
- **CMC panels utilizing DLR's liquid silicon infiltration (LSI) process**
  - Central post with flexible standoffs at the corners (thermal expansion not suppressed)
  - Fibrous matt insulation under cover plate
  - CMC fastener connects panel to central post.
- **C/C-SiC leading edge**
- **WHIPOX (Wound Highly Porous Oxide) seals**
  - Oxide fibers (Nextel) embedded in porous mullite or alumina matrix
- **Passenger experiments**
  - 2 ceramic (EADS)
  - 2 metallic (Plansee)
  - Ceramic (MT Aerospace)
- **Aluminum structure**
- **All in-flight instrumentation integrated into TPS**



Sustained Hypersonic Flight Experiment (SHyFE)

- **Funded by UK Ministry of Defense**
- **Objective**
  - Design and fly a prototype ramjet capable of sustained hypersonic flight
- **Vehicle**
  - Weight ~ 30 kg, 1.5 m long, 7 in. dia.
  - Sounding rocket boost to M 4 at 15 km, accelerate to M 6 at 32 km, cruise for 200-300 km
  - Ballistic climb from M 4 to M 6 that takes ~ 60 sec.
  - Diesel fuel
  - Shock on lip is M 4.8
- **First flight Aug 2009, second flight 2010**
- **Thermal management**
  - Minimize heat ingress from combustion chamber (2400K) to center body components
- **C/SiC used for vehicle construction**
  - MT Aerospace fabrication
  - Air-breathing propulsion experiment
  - Practically the entire flight exp is C/SiC, except a Ti tank
    - MT Aerospace is fabricating the C/SiC via CVI
    - The fuel flows in an annulus between 2 C/SiC tubes
    - The fin roots are bonded to the body
    - MT Aerospace has eliminated a lot of the bolts by bonding and some other creative techniques that they have not discussed





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AIAA-2006-7926
AIAA-2006-8071

LEA

- **MBDA and Onera (France)**
- **6 flight tests 2010 - 2013 in range of M 4-8**
- **4.5 m long**
- **Not recovered**
- **20-30 sec flight**
- **One of the key required technologies is fuel-cooled composite structures for combustion chambers**
  - C/SiC actively cooled combustion chamber being worked

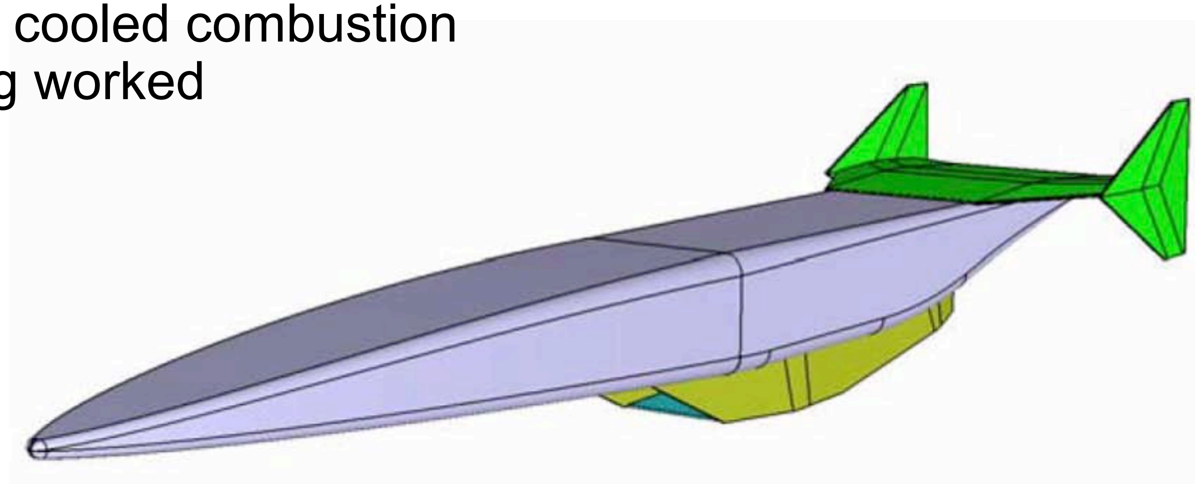
AIAA-2003-6918

AIAA-2005-3433

AIAA-2006-7925

AIAA-2006-8072

AIAA-2005-3434



LEA PTAH-SOCAR Actively Cooled Composites

- **MBDA / EADS ST**
- **Duct structure**
  - Obtained by weaving with stitching yarns through removable mandrel
  - 100 x 100 x 130 mm^3
  - Pin-fin coolant channel
  - No machining of channels (stitched)
  - Back-up structure required
  - 10 kg/m2, with backup structure 30% lighter than metallic cooled structure
  - Utilized CVI followed LSI (liquid silicon infiltration) for rapid (days vs weeks for CVI), low-cost densification
- **Hot test**
  - Cooled by air
  - Tested at M 7.5 conditions
  - Supersonic combustion air/H2
  - Twelve 10 sec tests
- **Next step - larger structures**

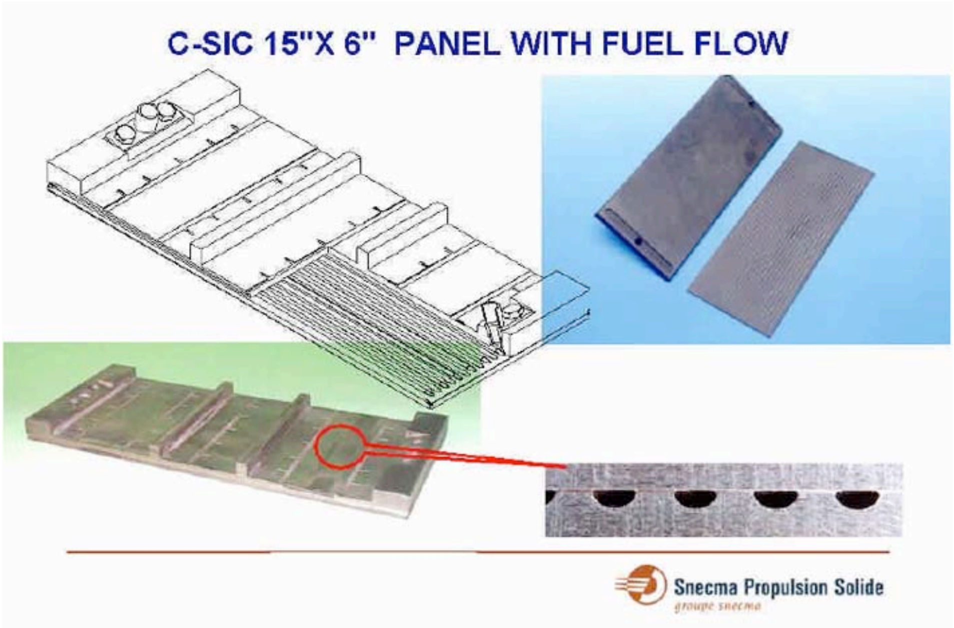
AIAA-2003-6918

AIAA-2005-3433

AIAA-2006-7925

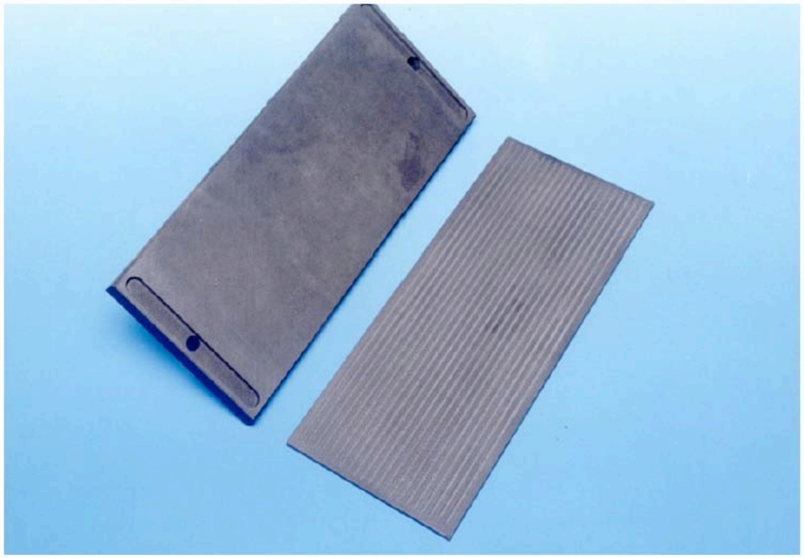
AIAA-2006-8072

AIAA-2005-3434

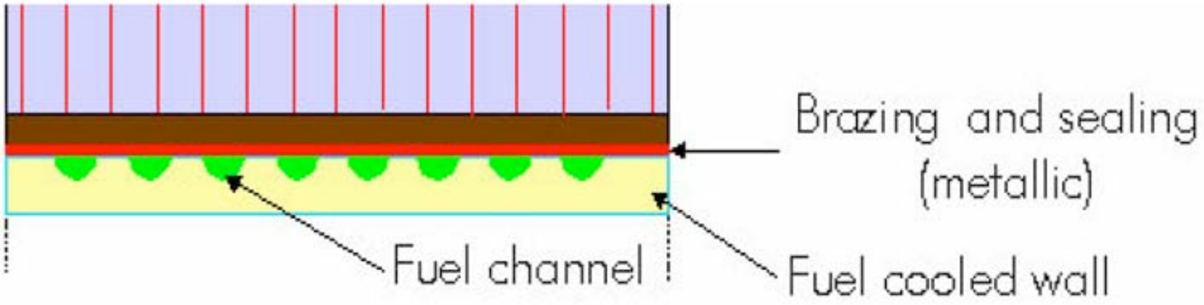


LEA CMC Cooled Combustion Chamber

- **Snecma and Onera (through PWR & AFRL, A3CP program)**
- **Snecma C/SiC (Sepcarbinox)**
  - Brazed 2 panels
  - Machined grooves in the hot side panel
  - Integrated manifolds on cold side
  - 115 x 40 mm with 3 channels

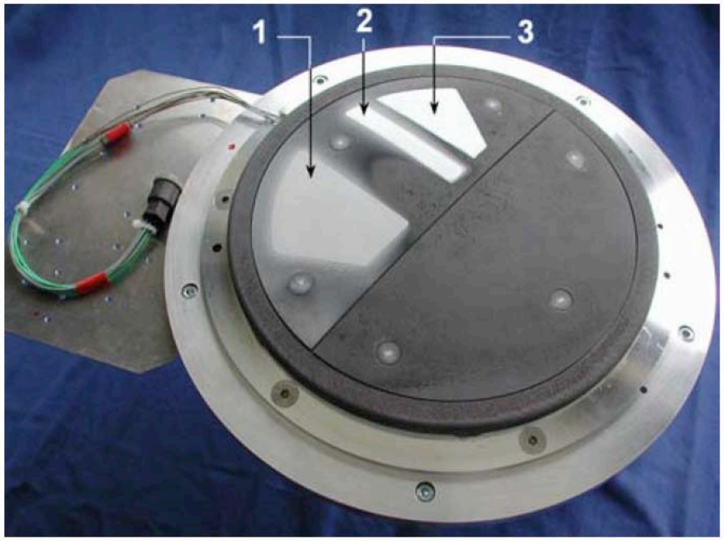


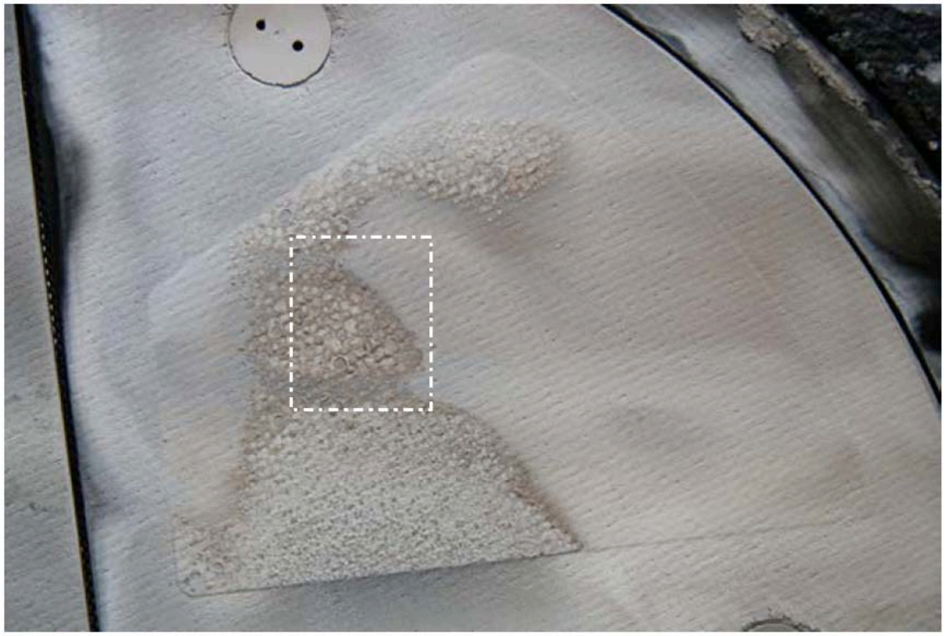
- **Tested at AFRL radiant facility**
  - JP7 fuel coolant
  - 1.21 MW/m^2 max heat flux
  - 6.9 MPa (1000 psi)
  - Good correlation with analysis
- **Same panel tested in an Onera scramjet engine test facility**
  - H2 for combustion
  - Up to 1.5 MW/m^2



DLR Coatings Flown on FOTON

- ♦ **FOTON is a Russian flight experiment (15 days in orbit)**
- ♦ **C/C-SiC via Liquid Silicon Infiltration (LSI)**
  - CFRP via process such as RTM
  - Pyrolysis at 900°C in Ar leads to porous C/C
  - Siliconizing at 1600°C in vacuum includes LSI and formation of SiC matrix
- ♦ **Developed yttrium silicate coating**
  - Performed well in PWT tests
  - Flew on FOTON
    - **1 and 2, CVD SiC + yttrium silicate via low pressure plasma spray**
    - **3, CVD SiC + titanium oxide slurry via "painting"**





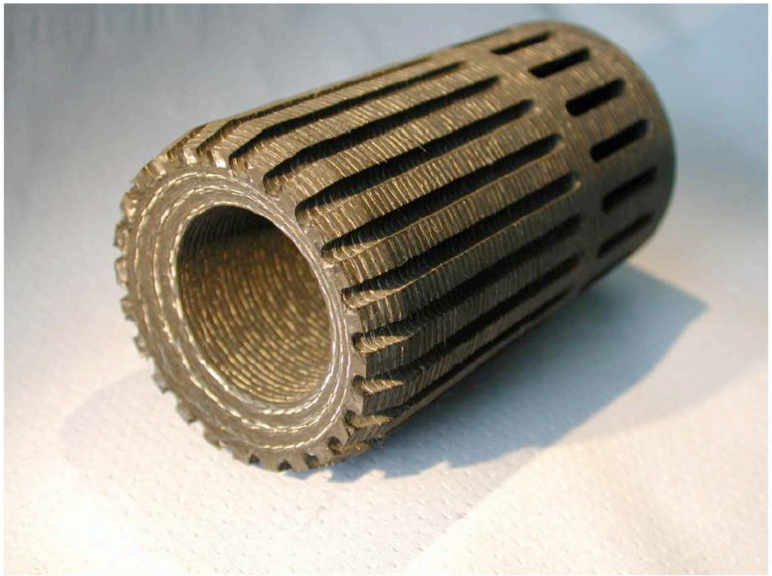
FOTON and EXPERT

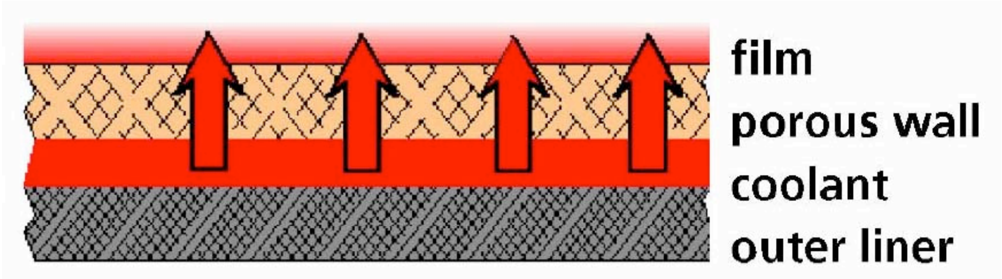
Agenda

- **Background**
  - Comments on prior ESA workshop
  - X-38
  - Hopper
- **Flight Vehicle Based Technology Development**
  - IXV (ESA)
  - EXPERT (ESA)
  - USV (Italy)
  - SHEFEX (Germany)
  - SHyFE (UK)
  - LEA (France)
  - Foton (Russia)
- **Non-Vehicle Specific Technology**
- **Concluding Remarks**

Actively Cooled CMC Thrust Chamber (DLR)

- **C/C used for inner material, porosity 13-22%**
  - 0°/90° lay-up
  - 10 mm thick
  - Temperature gradients 1000°C/mm due to low k (1-1.2 W/mK)
  - 30 mm chamber diameter
- **CFRP jacket**
  - Internal pressure loads
  - Longitudinal compression loads due to attachments and thrust
  - 5 mm thick
  - Searching for H2 barrier
- **Permeability of multiple CMC's measured**
- **Numerous hot tests performed**

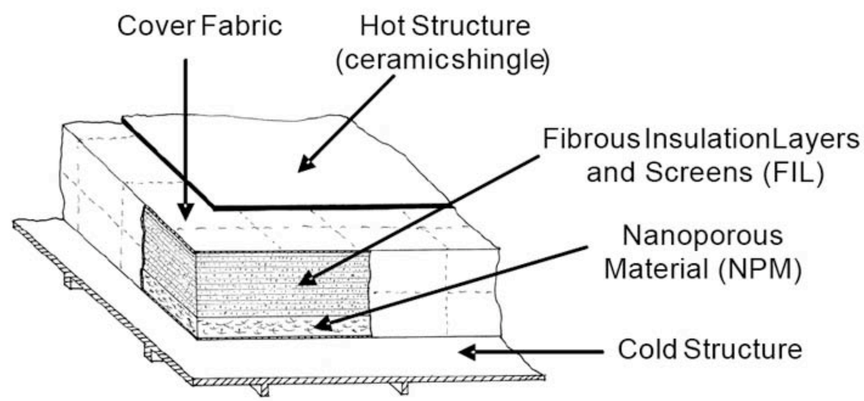


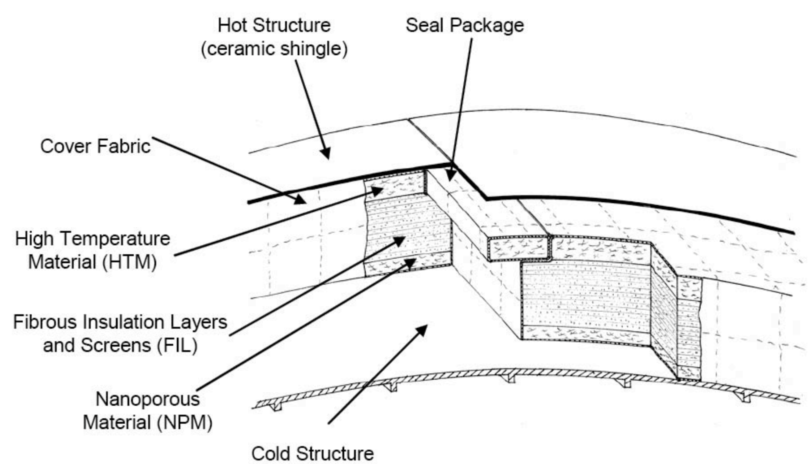


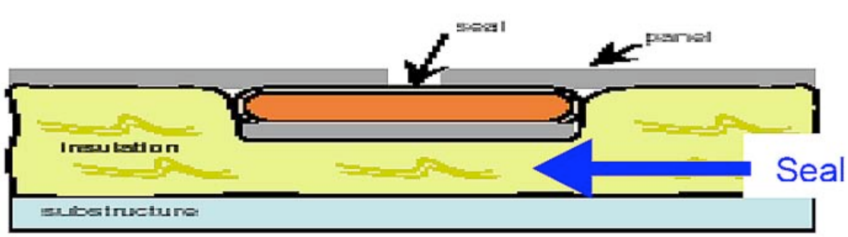
AIAA-2005-3229
ESA-TPS-2006-Kuhn

Multi-Layer Insulation (MT Aerospace)

- **Medium Temperature (~1000°C)**
  - Weight limit (by ESA) of 4 kg/m^2 and 40 mm thick
  - Nextel 312 fabric containment
  - Pryogel superior to Microtherm (density, vibration, humidity, handling)
  - Consists of IMI and Pyrogel (6 mm)
- **High Temperature (~1600°C)**
  - ESA limits: 80 mm, 8.5 kg/m^2
  - Nextel 440 fabric containment
  - IMI with Zircar APA-2 for highest temperature regions and Pyrogel for lower temperature regions.
- **Seals (DLR)**
  - Saffil filled Nextel 312 bag impregnated by MTMS (up to 1300K)
  - Saffil filled Nextel 440 bag impregnated by MTMS (up to 1900K)
  - Kept in place by C/SiC guard



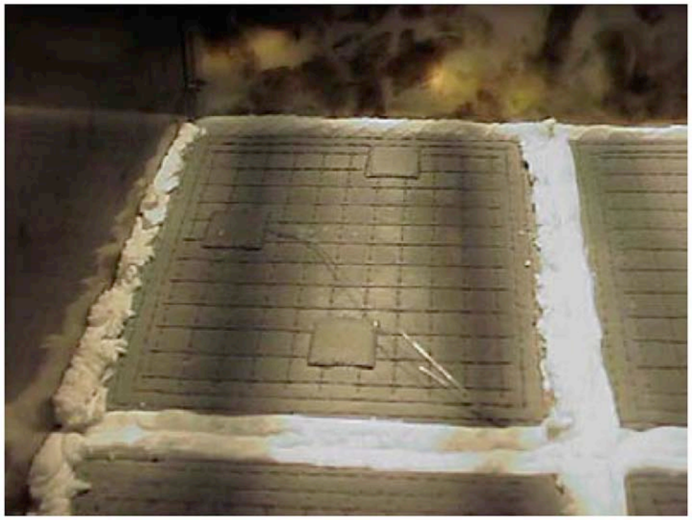




Flexible External Insulation (FEI) (EADS)

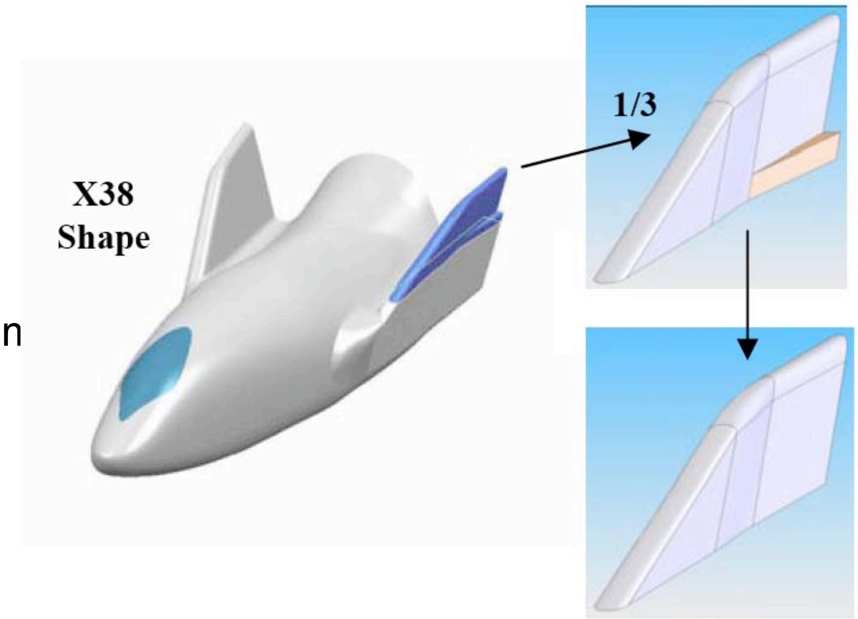
♦ **Improvement of FEI blankets**

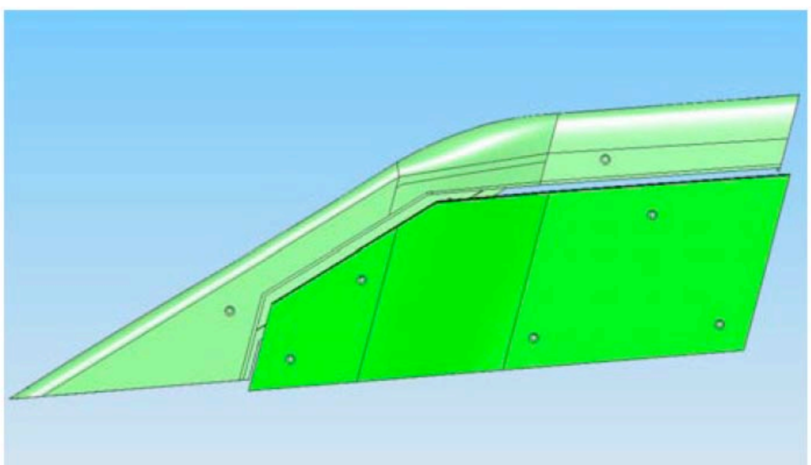
- New high emittance coating developed with improved stability
- New less toxic waterproofing for initial and re- waterproofing
  - **Preferred MTES (methyl triethoxy silane) over standard MTMS (methyl trimethoxy silane)**
- Refurbishment and repair procedures defined
- Applied to FEI-1000 blankets and subjected to environmental testing for 10 flights.
  - **Waterproofing and coating refurbished after 4 cycles**

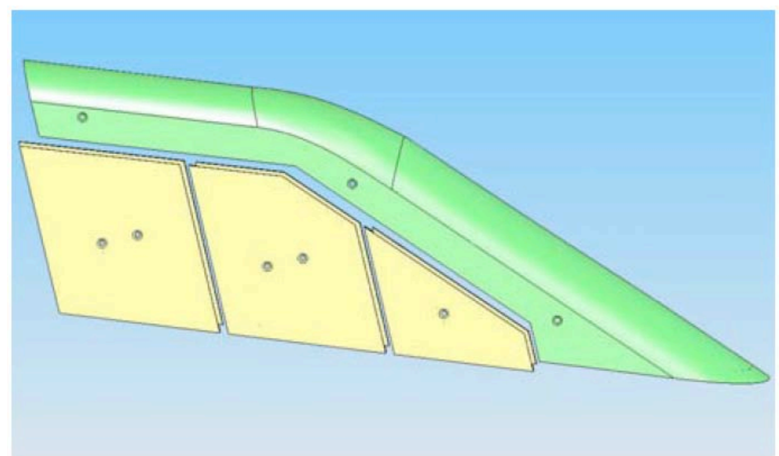


Hybrid Metal/CMC Winglet Hot Structure (Alenia)

- **Design and analysis complete**
- **1/3 size of X-38, removed hinge step**
- **Outboard panel and wing leading edge**
  - MT Aerospace C/SiC, 3 mm thick
- **Inboard panel divided into 3 panels**
  - Plansee PM 2000, 1 mm thick with 2 mm thick ribs
- **Seals**
  - Nextel wrapped saffil
- **Fabrication and PWT test planned**

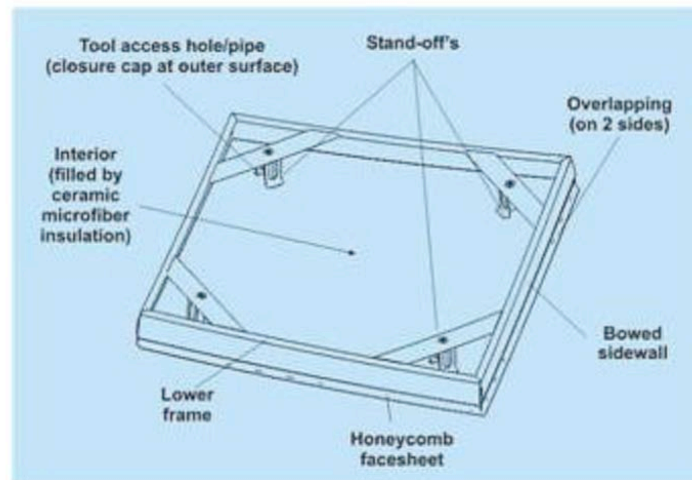






ULTIMATE Metallic TPS (EADS)

- **EADS (Astrium)**
- **Load carrying metallic box with standoffs and internal insulation**
  - Outer surface honeycomb sandwich (10 mm thick, hexagonal cells)
  - TiAl ?
  - Omega standoffs
- **Fabrication and test**
  - 200 x 200 mm (final design 500 x 5
  - Single panel test
    - **Vibration**
    - **Acoustic**
    - **Thermal test to ~850°C**
  - Assembly tests
    - **Vibration**
    - **Thermal IR**
    - **PWT**
- **SHEFEX flight**
  - Similar to ULTIMATE design



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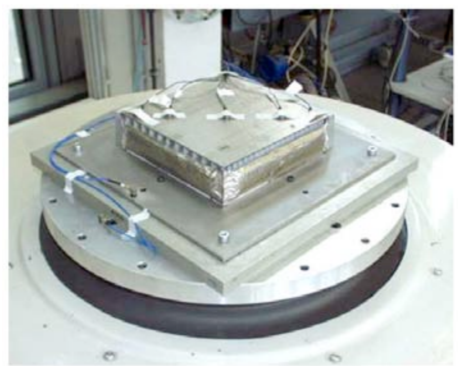
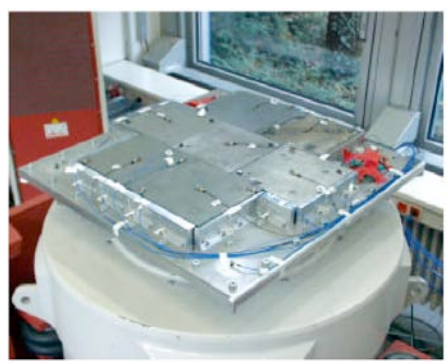
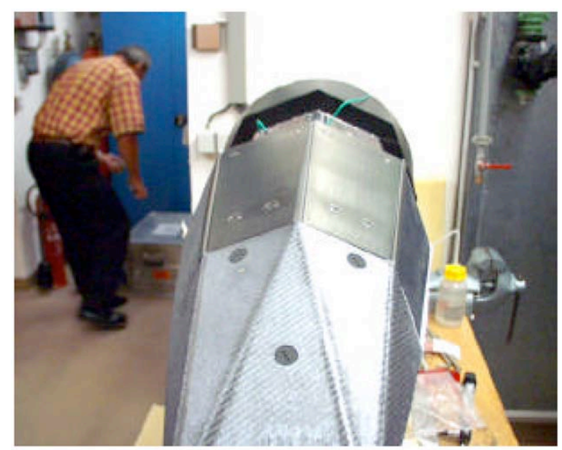


	Test Objectives	Test Conditions	Sample Definition	Number of Samples
Vibration Test	to characterise the mech. behaviour under vibrational loads	HOPPER loads	Single test panel 200x200 mm	1
Acoustic Test	to verify the mech. behaviour under acoustic loads	Re-entry vehicle spectrum	Two test panels 200x200 mm	(3)
Thermal Test	to verify the thermal behaviour under simulated reentry loads and to measure some basic thermal characteristics	IR test with Tmax=850°C (simulated integral thermal re-entry load)	Single test panel 200x200 mm	1
Plasma Test	to verify the thermal behaviour under reentry loads and study the panel-to-panel I/F and sealing	Re-entry profile with Tmax=850°C	T-gap panel cut-out max. 200x270 mm	(2)
Vibration Test	to verify the mech. behaviour of TPS assembly under vibrational loads	HOPPER loads	Array consisting of 200x200 mm panels	7
Thermal Test	to verify the thermal behaviour under simulated reentry loads and to measure global thermal characteristics (I/F & sealing)	IR test with Tmax=850°C (simulated integral thermal re-entry load)	Array consisting of 200x200 mm panels	7

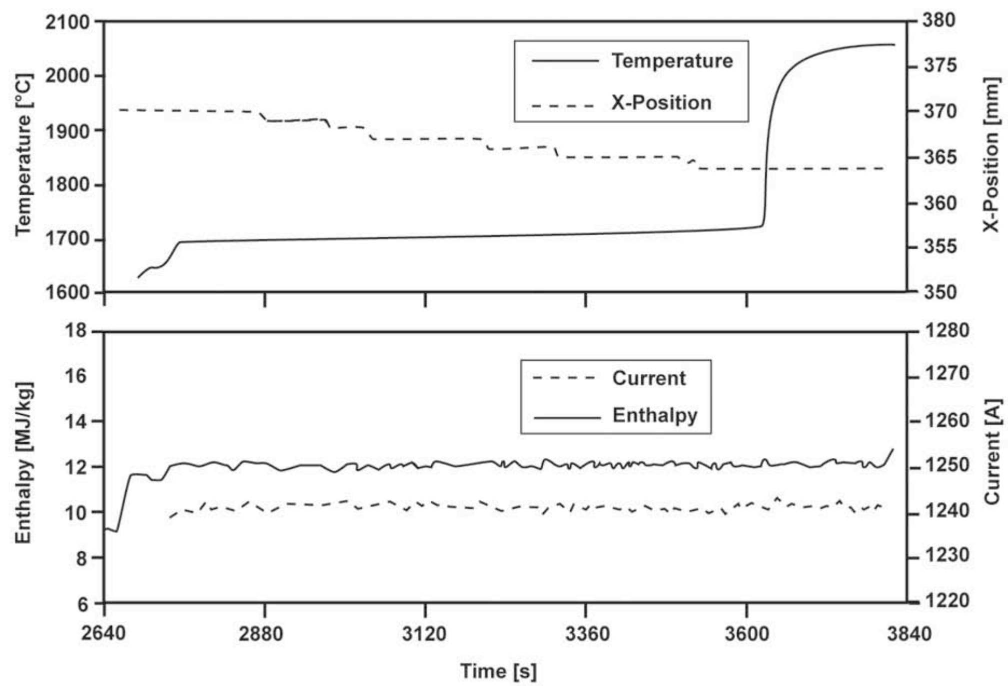
Table 1: Ground Test Matrix





Passive To Active Oxidation (Germany)

- **PWT tests ranging from 50 - 7000 Pa and 1650 - 1950°C with peak to 2300°C**
- **At steady state 1720°C/800 Pa, a small increment in energy (1 mm closer) caused a small hot spot that within 30 sec. covered the entire sample with a temperature of 2050°C**
- **Test very reproducible**
- **Also observed at 1700°C/50 Pa, 1800°C/2000 Pa, 1840°C/3500 Pa, 1940°C/7000 Pa**
- **Temperature jump occurring at passive to active transition**
- **What causes temperature rise?**
  - Test done with nitrogen plasma and little oxygen (few Pa)
    - 1460°C/690 Pa temperature rose to 1850°C with little erosion
  - Strong evidence of nitrogen recombination during active oxidation
  - Half energy released during active oxidation from oxidative reactions, half from nitrogen recombination



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Agenda

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  - SHyFE (UK)
  - LEA (France)
  - Foton (Russia)
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Key TPS & Hot Structures Players in Europe

- MT Aerospace - CVI C/SiC hot structures fabrication and design
- Plansee - High temperature metal (Ti, superalloy, and refractory metals) fabrication
- DLR - LSI C/C-SiC hot structures and general hot structures design
- Snecma - CVI C/SiC acreage TPS fabrication and design
- Dutch Space - metallic TPS and hot structures fabrication and design
- EADS/Astrium - complete portfolio of acreage TPS, TPS and hot structures design
- IABG - Hot structures testing
- ESTEC - ESA's "field center"
- CIRA - Italy's Aerospace R&D Center, world's largest PWT

Observations

- **Strong emphasis on CMC and metallic acreage TPS**
  - Europe considers CMC shingle TPS a higher TRL than metallic TPS. In the US, we have the opposite view.
- **In general, companies have niche technologies and little competition in that area, lots of collaboration**
- **Many of the companies have both the fabrication and design expertise in the same company**
- **They seem to be focused on developing technology for flight experiments**
- **They understand that flight experiments sometimes fail and move on**
- **Europeans are doing a lot of good work. Get papers and follow their progress**