Centro Italiano Ricerche Aerospaziali

Il programma SPACE RIDER: le protezioni termiche parlano italiano

Centro Italiano Ricerche Aerospaziali

Seminari Interdisciplinari di Cultura Aeronautica
II Serie, I Ciclo
4° incontro

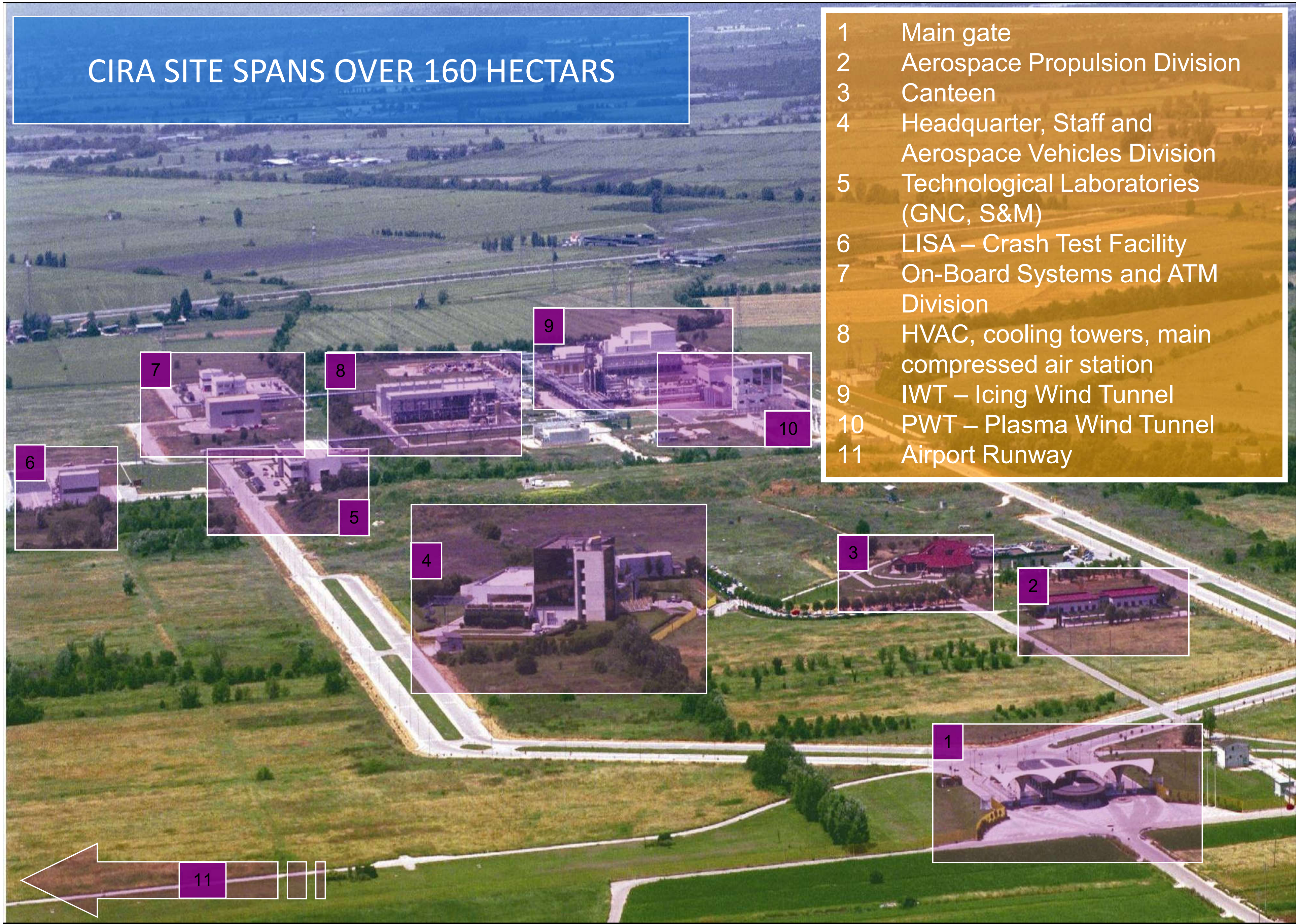
15 dicembre 2018
NELLO SPAZIO, INFINE

- Il CIRA e la Sperimentazione «Spaziale»
  - Plasma Wind Tunnel
  - Space Qualification Labs
- L'heritage nel settore del Rientro
  - USV
  - IXV
  - Space Rider
- Le Protezioni Termiche di Space Rider : un'avventura italiana
  - CMC flap
  - La Caratterizzazione in PWT

- A non-profit public-private partnership among:
  - ASI (Italian Space Agency) - 47%
  - CNR (National Council for Research) - 5%
  - Campania Region - 16%
  - Italian Aerospace Industries - 32%
- In 1989, the Italian Government entrusted CIRA of the Italian Aerospace Research Program (PRORA) management:
  - development and operation of strategic testing facilities,
  - development of strategic research programs,
  - enhancement of scientific competences and expertise.
- 370 employees and approx. 50 university students and PhD candidates a year
- Partner of the main European research programs in the aviation and space fields

CIRA SITE SPANS OVER 160 HECTARS

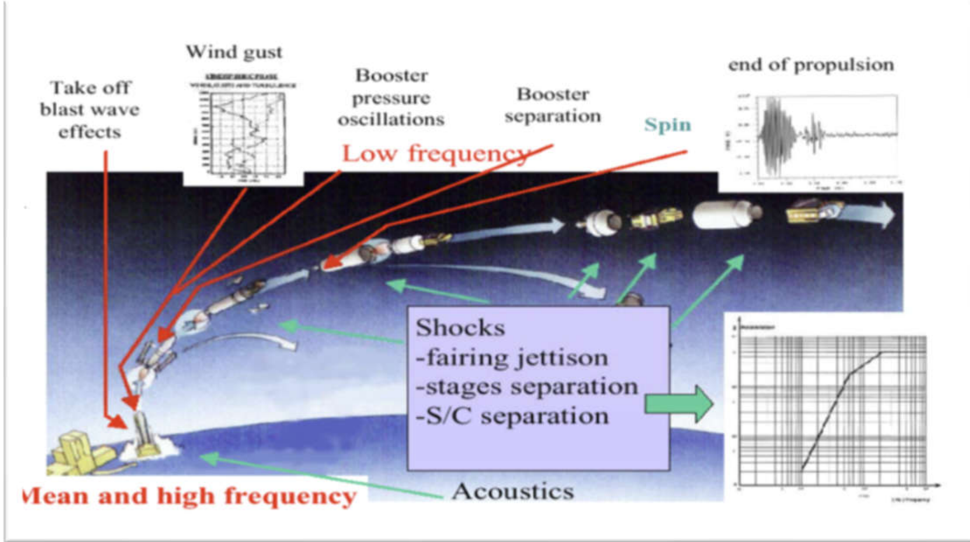
1 Main gate
2 Aerospace Propulsion Division
3 Canteen
4 Headquarter, Staff and Aerospace Vehicles Division
5 Technological Laboratories (GNC, S&M)
6 LISA – Crash Test Facility
7 On-Board Systems and ATM Division
8 HVAC, cooling towers, main compressed air station
9 IWT – Icing Wind Tunnel
10 PWT – Plasma Wind Tunnel
11 Airport Runway

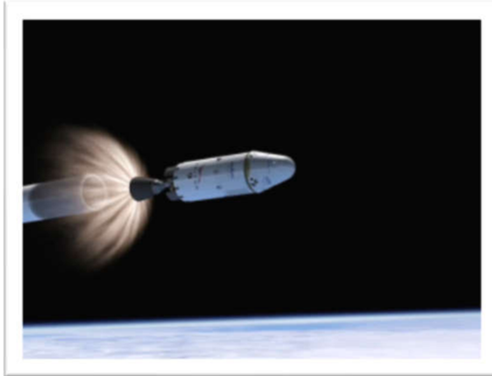


Spacecraft structures and internal equipment are exposed to a variety of mechanical, thermal, and electromagnetic loads.

The environments, relevant to both Earth and space missions, are :

- Radiation
- **Vibration**
- **Thermal**
- Electromagnetic





One of the challenges in space qualification is to reproduce the operational environment such that critical components are tested to the limits of a mission without requiring expensive overdesign.

CIRA Plasma Wind Tunnel Facilities

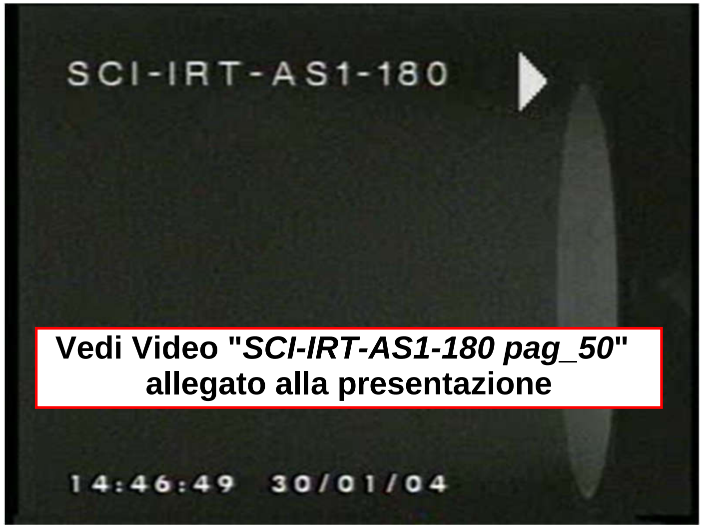
Steam Supply System (96,6 ton/h)

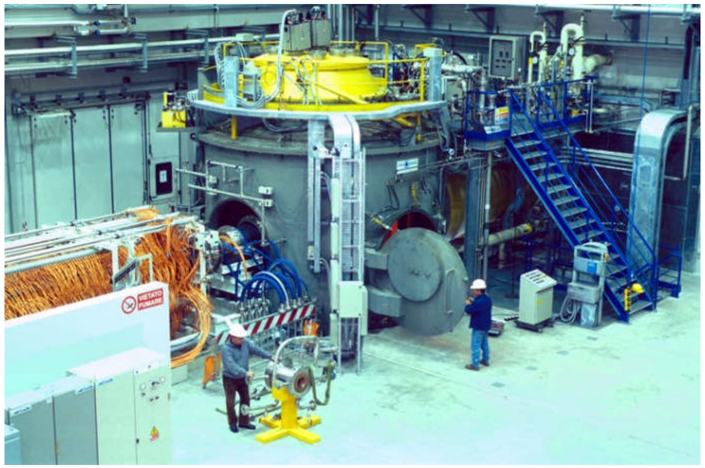
Electrical Energy Supply System (90MVA)

Tower Water Supply System (11700 m^3/h)

Compressed Air Supply System (3,5kg/s)

PWT – Plasma Wind Tunnel SCIROCCO





- Goal: Improve safety of re-entry space vehicles
- Use: Design and test thermal protection systems for space vehicles
- Operative since: 2002
- Testing fluid: air
- Max speed: Mach 16
- Stagnation temperature: ~ 10.000 ° C
- Max test durations: < 25 minutes
- Nozzle exit diameter: 2.0 m
- Nominal dimension of test specimen: 0.6 m
- Max power of arc heater: 70 MW

GHIBLI – SMALL PLASMA WIND TUNNEL SCIROCCO

- GOAL: IMPROVE SAFETY OF RE-ENTRY SPACE VEHICLES
- USE: DESIGN AND TEST SMALL SPECIMENS OF MATERIALS TO BE USED FOR THERMAL PROTECTION SYSTEMS OF SPACE VEHICLES
- TESTING FLUID: AIR, (CO_2 IS UNDER DEVELOPMENT)
- MAX SPEED: MACH 12
- STAGNATION TEMPERATURE: $\cong 10000\ ^\circ C$
- MAX TEST DURATIONS: < 25 MINUTES
- NOZZLE EXIT DIAMETER : 150 MM
- NOMINAL DIMENSION OF TEST SPECIMEN: 80 MM
- MAX POWER OF ARC HEATER: 2 MW

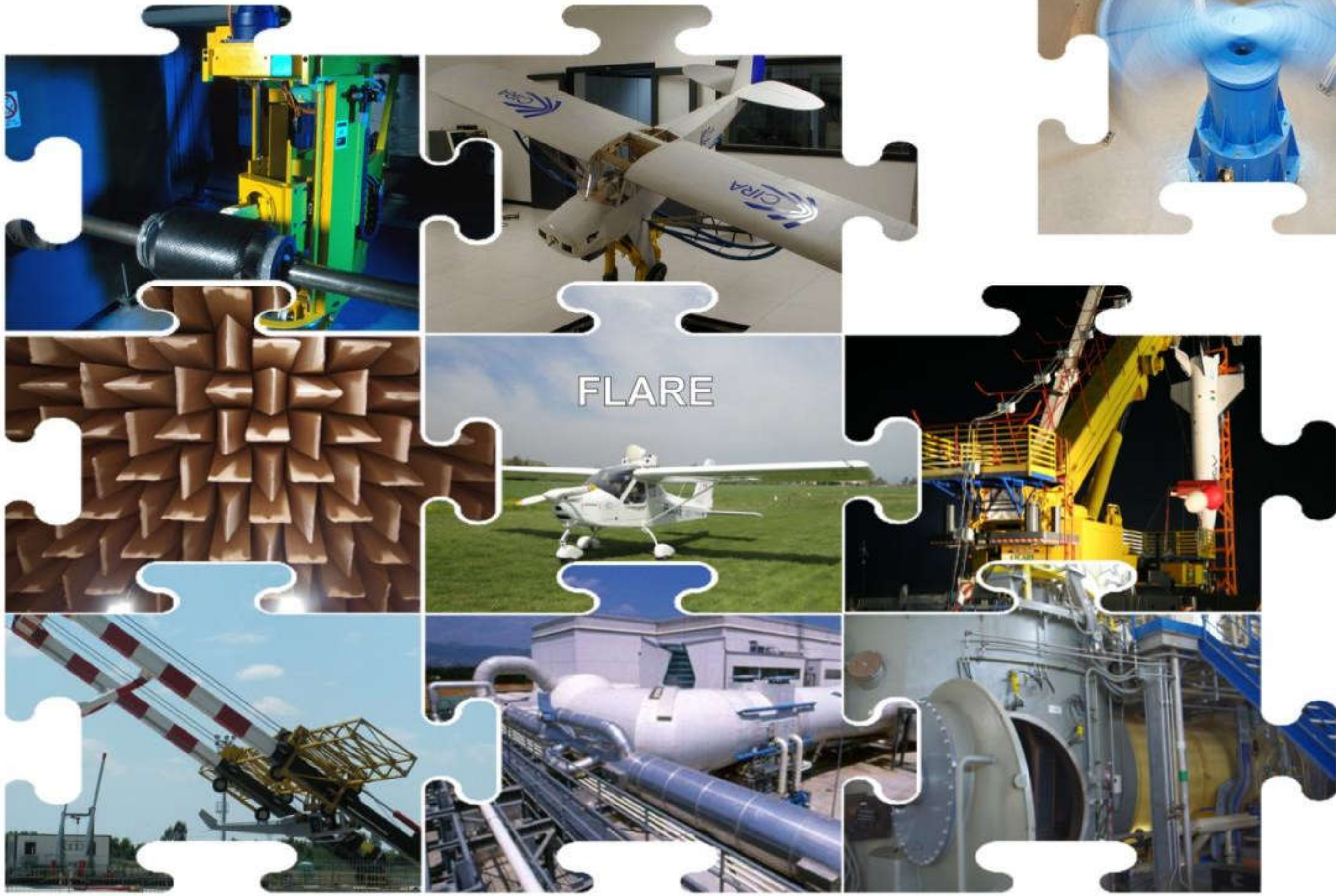
Space Qualification lab

Lab. Qualifica Spaziale

Lab. Materiali Avanzati

Lab. GN&C

Lab. Vibrazioni/Acustica



Unmanned Space Vehicle

Lab. Impatto al Suolo

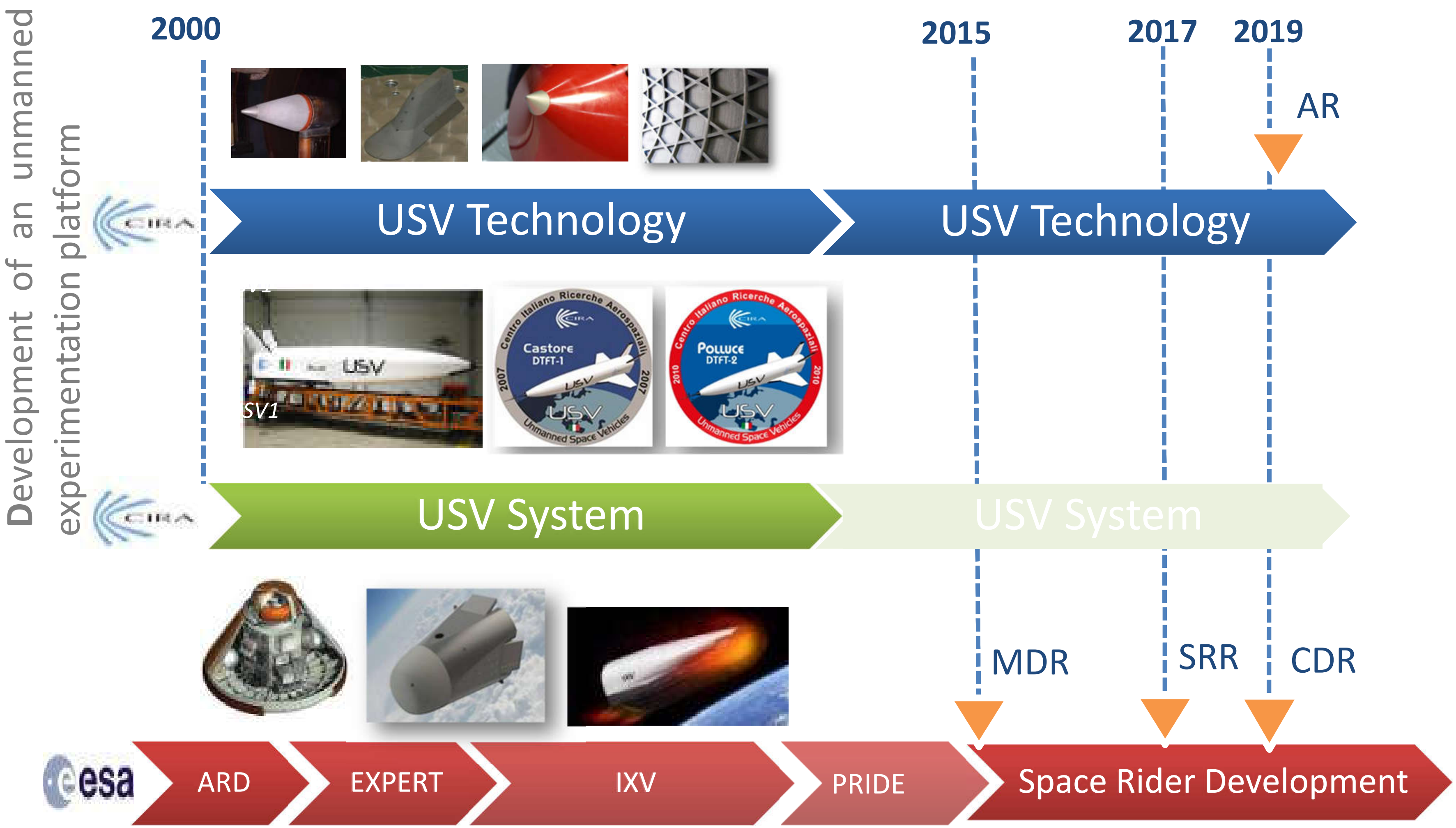
Icing Wind Tunnel

Plasma Wind Tunnel

- Qualification capabilities ESA ECSS E-10-03-A “Space Engineering – Testing” & MIL-STD 810F for:
  - Physical properties measurements
  - Acceleration test
  - Combined vibration, humidity, temperature and altitude test
  - Environmental stress screening
  - Thermal shock test
  - Thermal vacuum test
  - Pyroshock test
- Equipment under test (EUT) of nominal dimensions 400x400x400 mm and 20 kg weight
- Equipped with flanges and standard MIL connectors to link the EUT with an EGSE for the transmission of excitation and monitoring signals to verify the EUT functionalities during the test

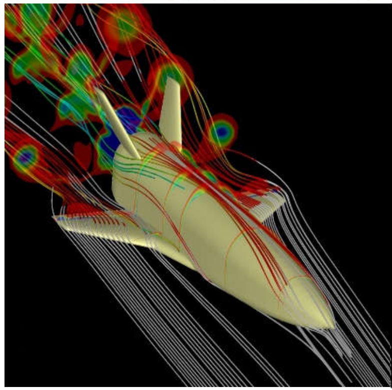
EXAMPLES OF TECHNOLOGY DEVELOPMENT AND INTEGRATION

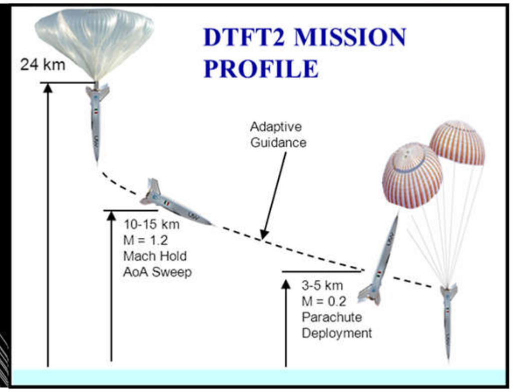
CIRA Unmanned Space Vehicle : more than 15 years of Italian research on re-entry technologies



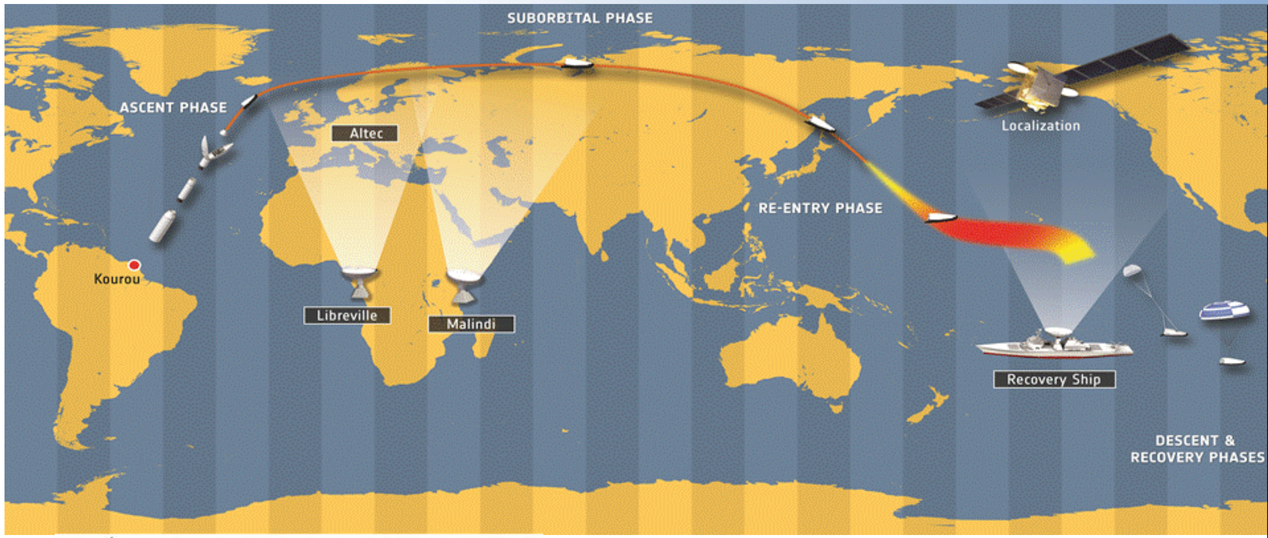
USV Programme

- **Objective**: development of an unmanned experimentation platform.
- **Scope**:
  - Validation of key enabling technologies : aerodynamics, aerothermodynamics, material, structures, guidance navigation and control.
  - Demonstration of system capabilities to perform “glided” re-entry from sub-orbital or LEO conditions.
- **1st Drop Transonic Flight Test:** 02/2007
- **2nd Drop Transonic Flight Test:** 04/2010



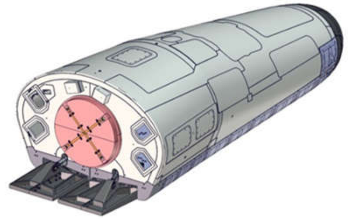


IXV Mission



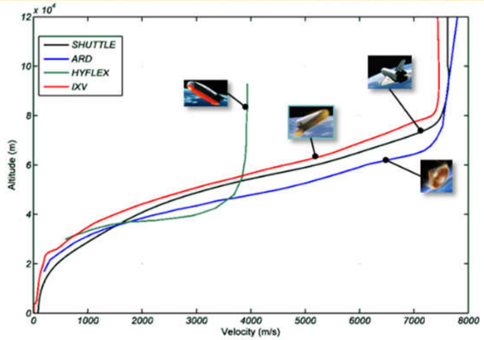
System Demonstration

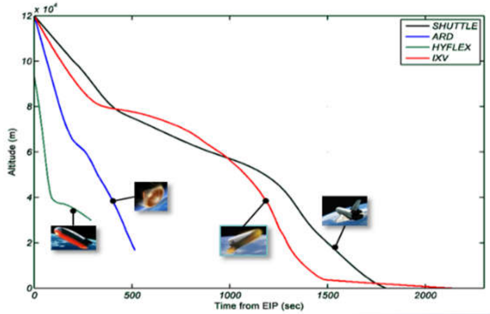
First lifting-body system flying a fully representative return mission from LEO world-wide

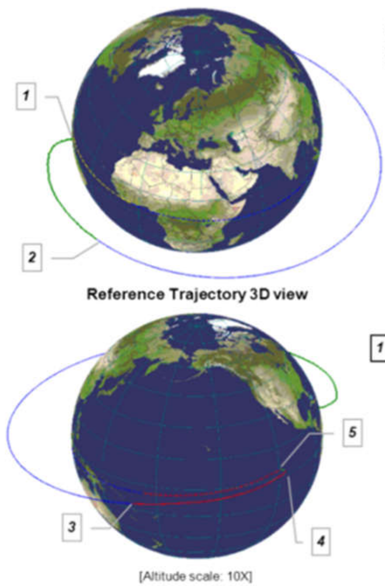


Technologies In-flight Verification

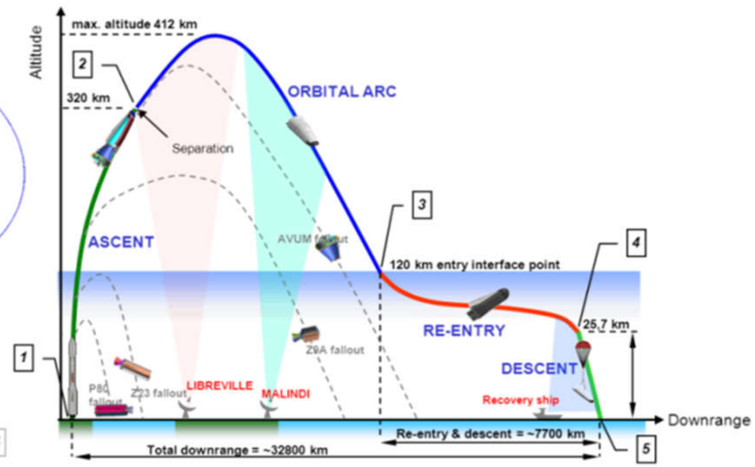
- Advanced thermal protections and hot structures (with ceramics and ablatives)
- Advanced guidance navigation and control techniques (with thrusters and aero-flaps)
- Advanced Aerothermodynamics investigation techniques (with ≥300 integrated sensors)







Reference Trajectory 3D view



Reference Timeline

1 – Lift off	T = 0 [s]	*Ascent segment*	*966 [s]*
2 – Separation	T = 966 [s]	*Orbital segment*	*2891 [s]*
3 – Entry gate	T = 3857 [s]	*Re-entry segment*	*1323 [s]*
4 – Descent gate	T = 5180 [s]	*Descent segment*	*881 [s]*
5 – Splashdown	T = 6061 [s]		

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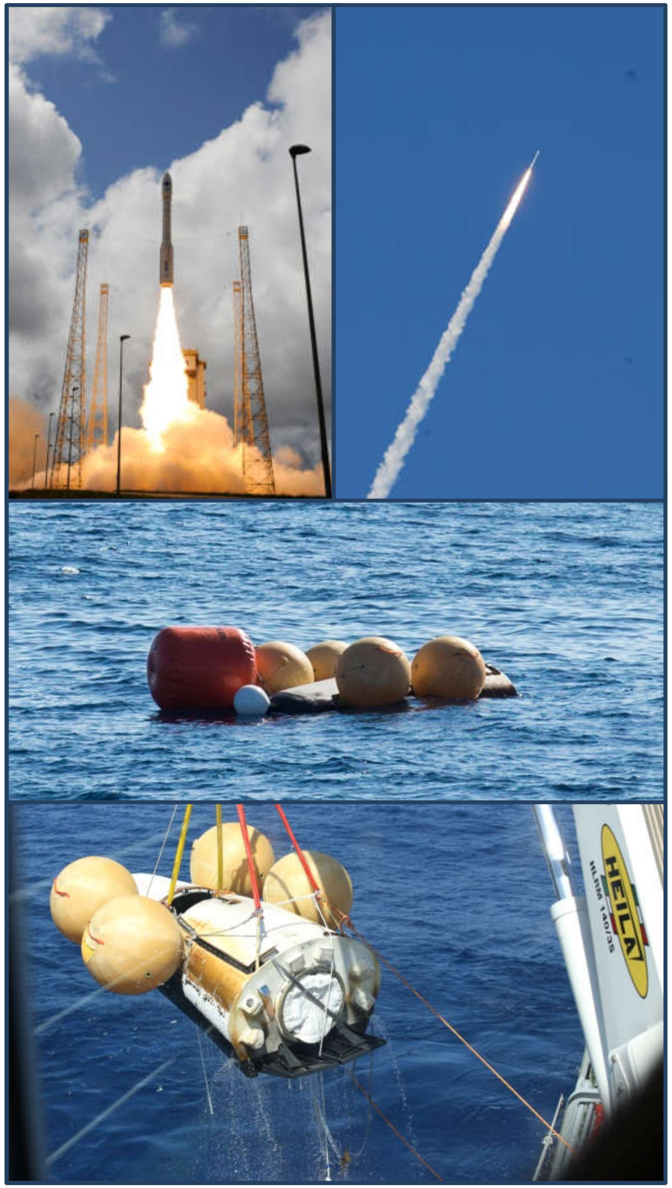
European Space Agency

IXV - THE MISSION EXECUTION

The IXV mission was successfully performed on the **11th of February 2015**, with all flight hardware and all flight data successfully recovered, through flight segment telemetry transmission and ground segment acquisition, and on-board recording, with the confirmation that the flight data is complete and consistent among the various sources.

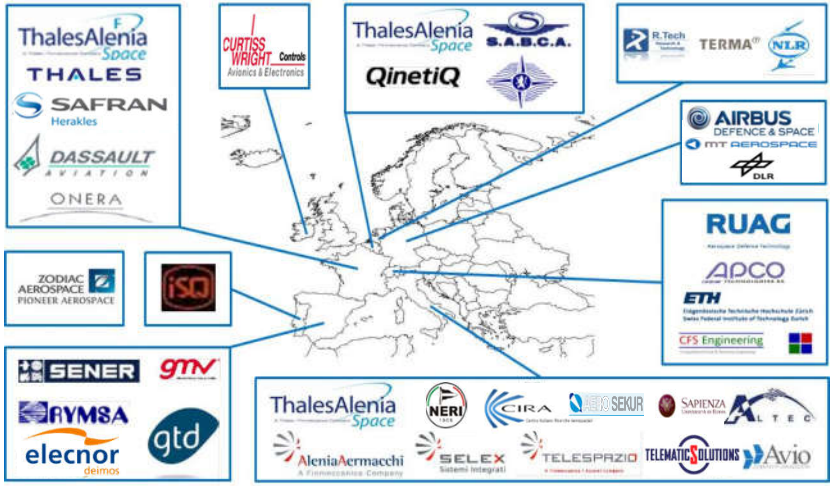
The IXV system, and all associated technologies, have successfully performed the whole flight program in line with the commanded maneuvers and trajectory predictions, performing an overall flight of approximately 25.000 km including 8.000 km in hot atmospheric re-entry environment with automatic guidance, starting from an orbital velocity of ~7.5 km/sec (Mach=27), concluding with precision landing.

100% of the IXV mission, system and technologies objectives have been successfully achieved.



CIRA Role in IXV

- **Engineering activities**
  - ✓ aerodynamics
  - ✓ aerothermodynamics,
  - ✓ technologies demonstration in flight
  - ✓ thermal protection systems qualification
- CIRA specialists were part of the ESA team during the **IXV development, launch and mission execution.**
- **Design and execution of the drop test** performed from a helicopter of an IXV prototype scale 1:1; the goal was to test parachute and buoyancy safety system.
- **IXV Post Flight Analsysis**

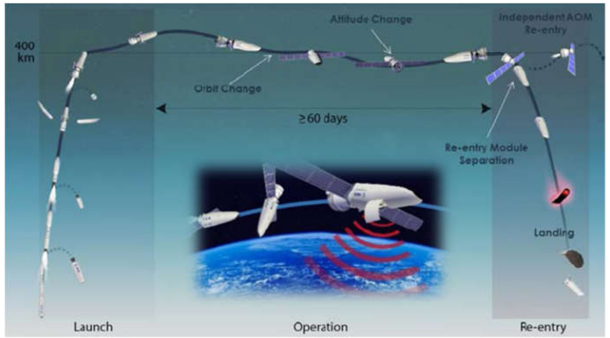


agenzia spaziale italiana

IXV EXHIBITION IN CASERTA ROYAL PALACE, JUNE-JULY 2015

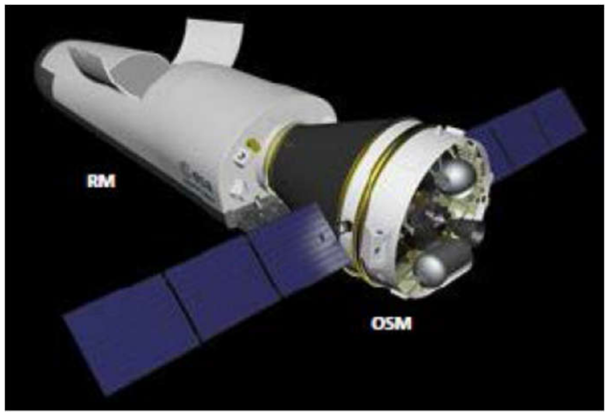
Goals:

- To develop an **affordable and sustainable** reusable European space transportation system:
  - to enable **routine access to and return from space**
  - to provide a **standardized platform for Payloads** for multiple space application in a multitude of orbits
- To focus on the **demonstration of a recurring service**.



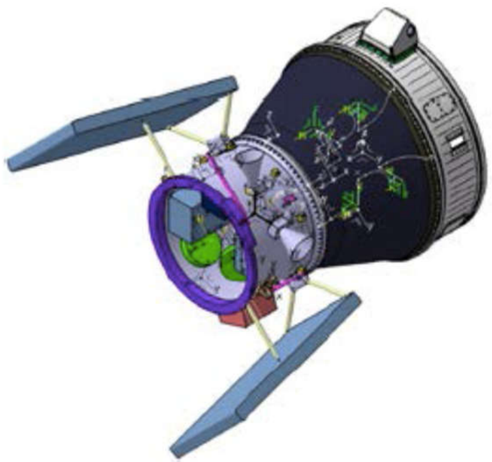
Main Mission scenario:

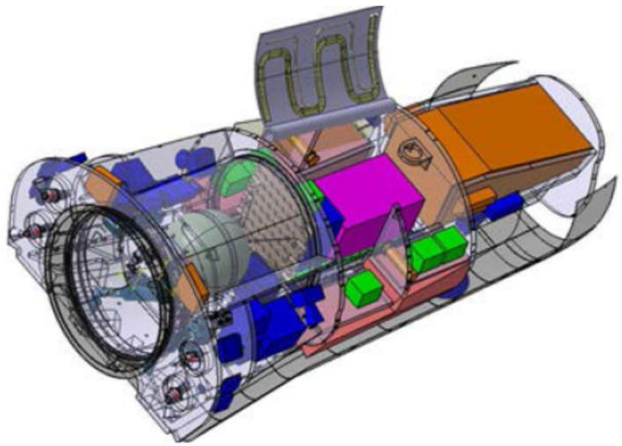
- **Free Flyer:** Microgravity Lab
- **In Orbit Demonstration:**
  - Exploration (e.g. robotics)
  - Earth observation (e.g. instrumentation);
  - Others (e.g. Earth science, telecommunication).
- **Surveillance applications** (e.g. earth monitoring, satellite inspection)
- Phase-B1 completed in December 2017
- Activities for Phase-B2/C started on January 2018: System PDR in Q4 2018



MAIN SYSTEM FEATURES

- Launched with VEGA C and injected in LEO. Reference orbit for max payload: (400 km – 5deg).
- Payload mass larger than 650 kg for the reference orbit.
- Payload volume larger than 1.0 m3.
- In-orbit operational capability of at least 2 months.
- Precision ground landing allowing fast payload recovery time.
- Main landing site on European territory.
- System reusability with minimum refurbishment for 6 missions





OUTLINE

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    - Plasma Wind Tunnel

- L'heritage nel settore del Rientro
    - USV
    - IXV
    - Space Rider

- Le Protezioni Termiche di Space Rider : un'avventura italiana
    - CMC flap
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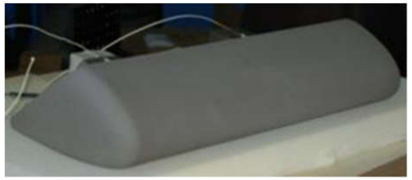
EXAMPLES OF UHTC MASSIVE

Since 2000, in the framework of the national aerospace research program (PRORA-SHS) and within various other National and European programs, CIRA together with CNR-ISTEC have studied, developed, and tested monolithic UHTCs and, in cooperation with CSM, UHTC coatings on different high temperature structural materials.

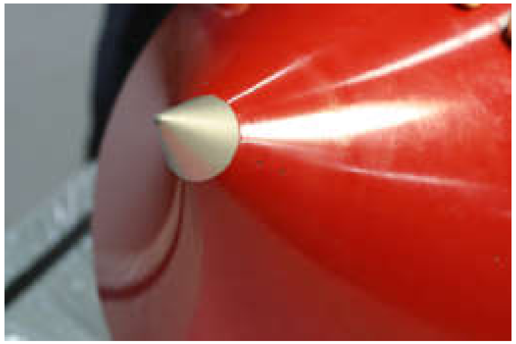
Small winglets and nose made in UHTC (EXPERT and SHARK project) or UHTC coated (SCRAMSPACE project) were designed, manufactured and installed on rockets or re-entry vehicles for in-flight qualification. Unfortunately, only the SHARK nose tip experienced the flight environment.



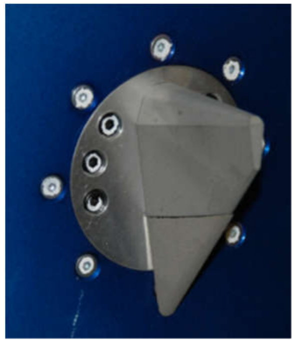
ASA
WLE Demonstrator made of CMC coated with UHTC

SHS
Nose Cap Demonstrator: the tip is made of massive UHTC

EXPERT
Structural aerodynamic profile made of massive UHTC ; UHTC-METAL I/F



SHARK
Structural aerodynamic profile made of massive UHTC



SCRAMSPACE
Structural aerodynamic profile made of metal UHTC coated and massive UHTC

Examples of UHTC Coatings

- Massive UHTCs have proven extreme thermal resistance and chemical stability but the low toughness and low machinability make very hard to realize large and complex components.

- UHTC coating can improve the performances of some refractory metal or CMC that can withstand very high temperature, but that suffer erosion because oxidation.

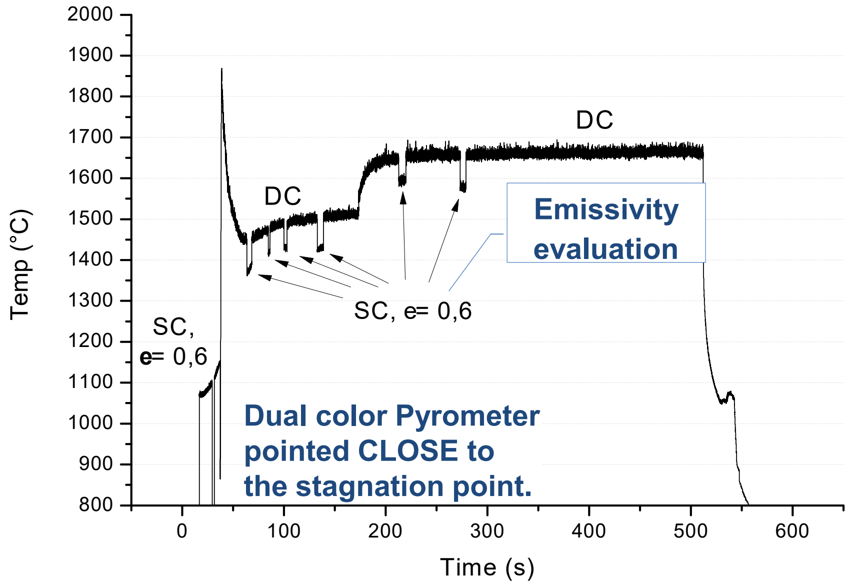
Combination of refractory metallic substrate and UHTC coating able to withstand:

- up to 1700°C
- for more than 7 minutes
- for more than one test
- without erosion

The tests have also shown that when the coating exceeded its working temperature, the failure stays localized in the overheated region, without propagations.

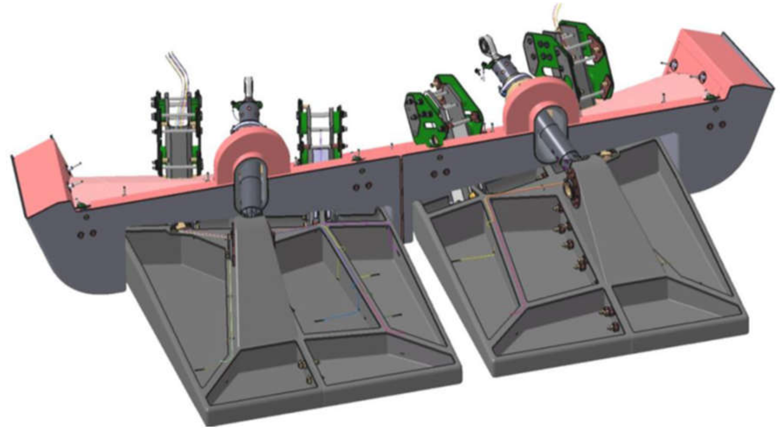
UNTESTED **TESTED** **UNCOATED**

The samples survived temperature exceeding 1700°C for several minutes with no erosion.



IXV Body Flap Assembly by MT Aerospace

Keraman®

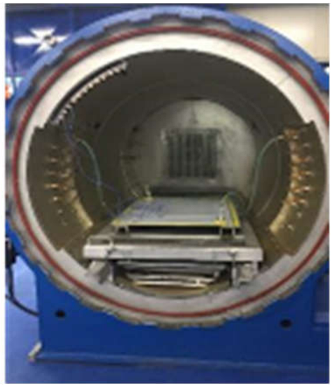


PRIDE Control Surface Assembly by ?

Italian Research Consortium

CIRA HERITAGE
TPS

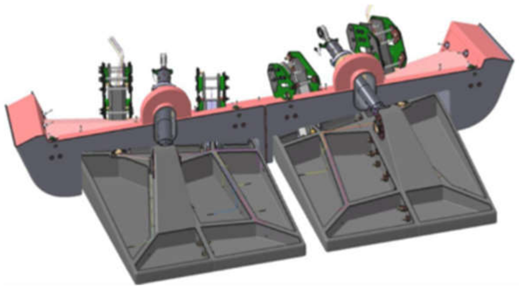
Since 2016, CIRA is leading a consortium of Italian excellence in the ceramic materials sector for the manufacture of C/SiC components with low cost techniques based on the Pyrolysis + LSI + Coating of SiC processes.



Pyrolized CFRP

CMC

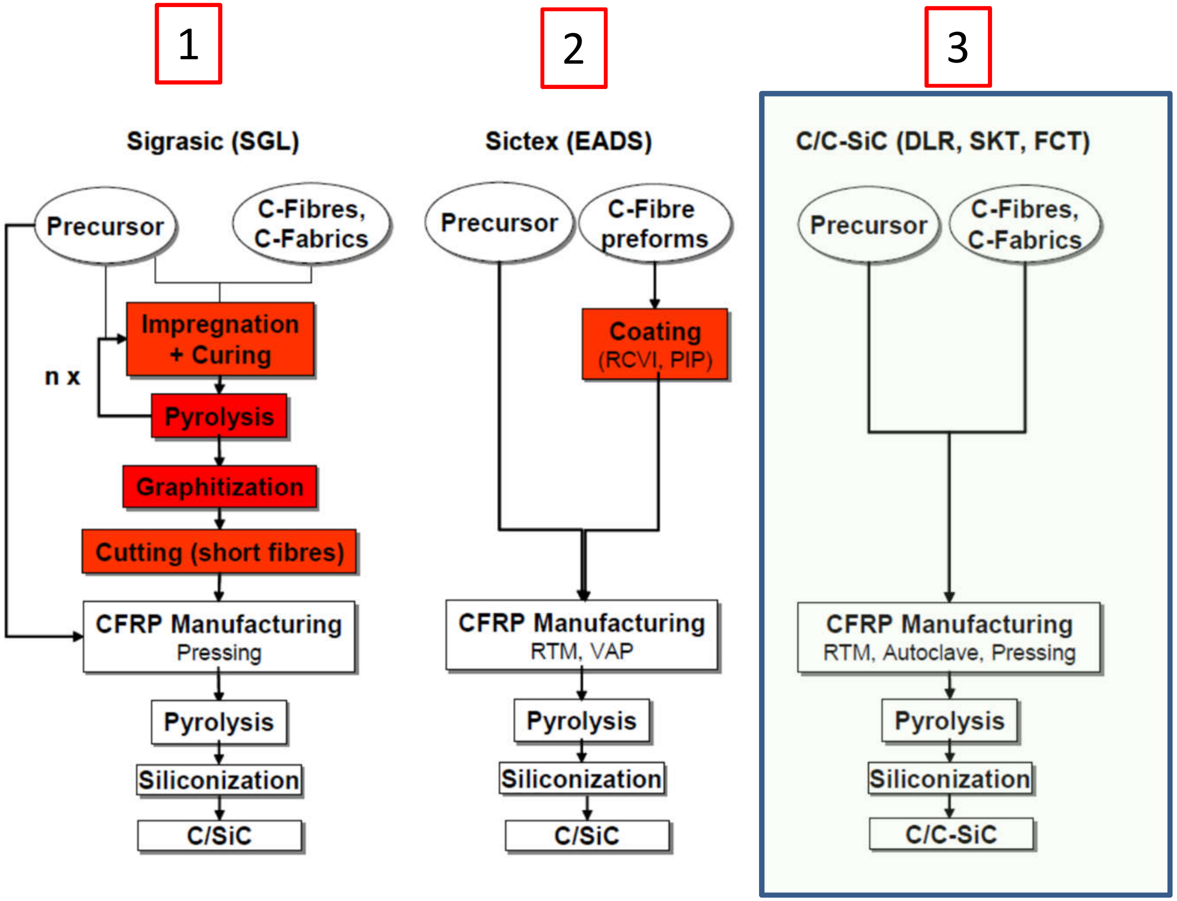
Pyrolised and siliconized phenolic base CFRP samples (CIRA / Petroceramics)



PETROCERAMICS

brembo

Liquid Silicon Infiltration (LSI) / Melt Infiltration (MI) Manufacturing Processes are based on 3 different methods to assure fibre protection and weak fibre/matrix bonding



EXPERT NOSE fabricated by DLR

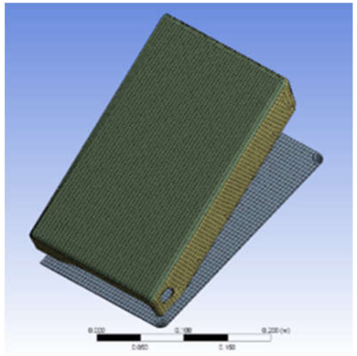
New Italian Process

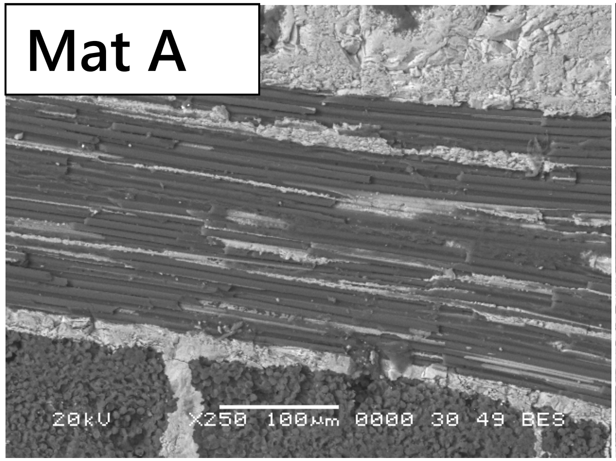
ISiComp®

Surface Treatment for Re-entry HS

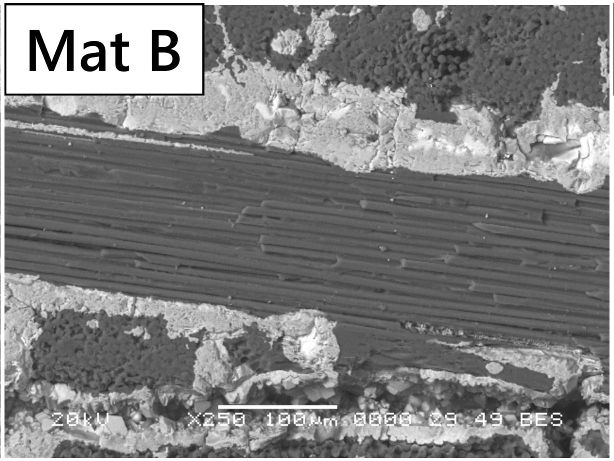
a) In situ fibre protection using Si vapor produced during LSI process.

- **MATERIAL SELECTION:**
  - Phenolic prepreg fabric manufactured in Italy coupled with different type of fibers (following a trade off)
- **CFRP:**
  - different autoclave routes to set up the optimal process parameters (pressure, lay up, thermal cycles) vs properties and geometrical contraints
- **PYROLYSIS**:
  - test of different pyrolysis cycles to set up the optimal process parameters (time, temperatures)
- **SILICONIZATION**:
  - Si infiltration to set up set up the optimal process parameters (time, temperatures)
- **SEM, THERMAL AND MECHANICAL CHARACTERIZATION**
- **THERMO-MECHANICAL MODEL SET-UP AND VALIDATION**

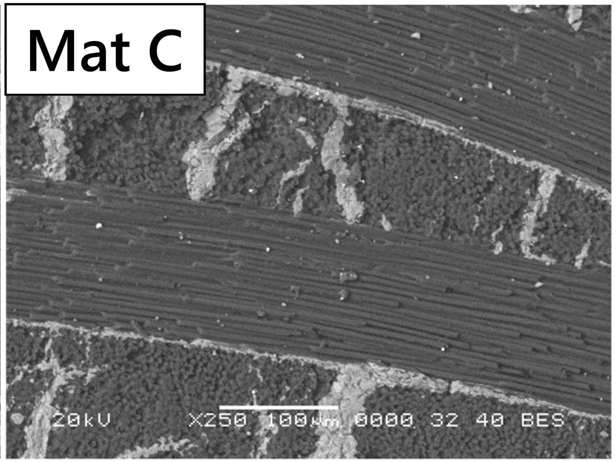




bundles silicon infiltration



Slight bundles silicon infiltration



No bundles silicon infiltration

Low overall silicon infiltration

Mechanical properties increasing

RESULTS : MATERIAL SELECTION & PROCESS SET UP

Composite features vs mechanical properties

High fracture toughness

- No bundles silicon infiltration
- Fibers and bundles pullout
- Quite low fiber-matrix adhesion

Low fracture toughness (brittle behaviour)

- Bundles silicon infiltration
- Too high fiber-matrix adhesion

RESULTS : MATERIAL CHARACTERIZATION

PROPERTY of the selected material (Resin/Fibers)	VALUE
E-Modulus	56 Gpa
Tensile strength	150 Mpa
Flexural strength	200 MPa

Table 5.4 Material properties of fabric and short fiber reinforced C/C-SiC and C/SiC material variants, obtained by LSI (DLR, SGL, SKT).

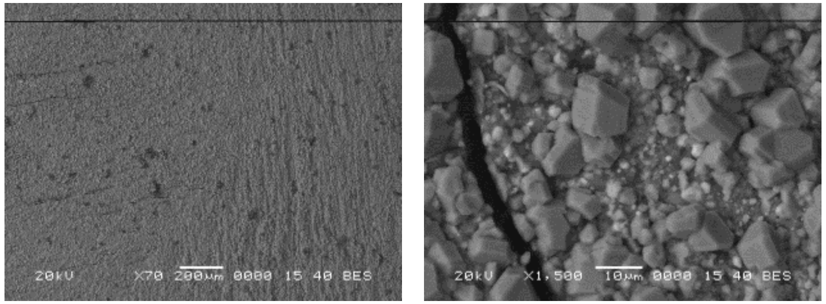
Material properties		Unit	C/C-SiC XB	C/C-SiC XT
Manufacturer		–	DLR	DLR
Fiber reinforcement		–	Fabric	Fabric
Density		$g cm^{-3}$	1.9	1.92
Open porosity		%	3.5	3.7
Young's modulus[a]		GPa	60	100
Flexural strength		MPa	160	300
Tensile strength		MPa	80	190
Strain to failure		%	0.15	0.35
Thermal conductivity[a]	‖	W/mK	18.5/17	22.6/20.8
	⊥		9.0/7.5	10.3/8.8
Specific heat (25 °C)		$J kg K^{-1}$	750	690
SiC content		vol.-%	21.2	19.8
Si content		vol.-%	5.4	4.1
C content		vol.-%	69.9	72.4
CTE	‖	$10^{-6} K^{-1}$	–1/2.5[d]	–1/2.2[d]
Ref. Temp. = 25 °C	⊥		2.5/6.5[d]	2.5/7[d]

‖ and ⊥ = fiber orientation.
a 0–300 °C/300–1200 °C.
b 20/1200 °C.
c 25–800 °C.
d 100/1500 °C.
e 25/1400 °C.
f 50 °C.
g 200/1600 °C.

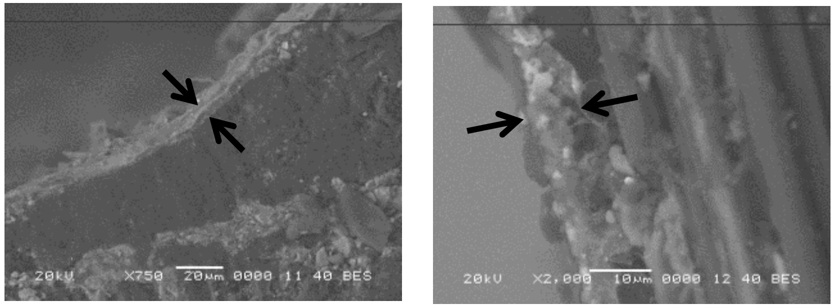
Expert Nose
manufactured using C/C-Sic XB material

RESULTS : COATING EVALUATION

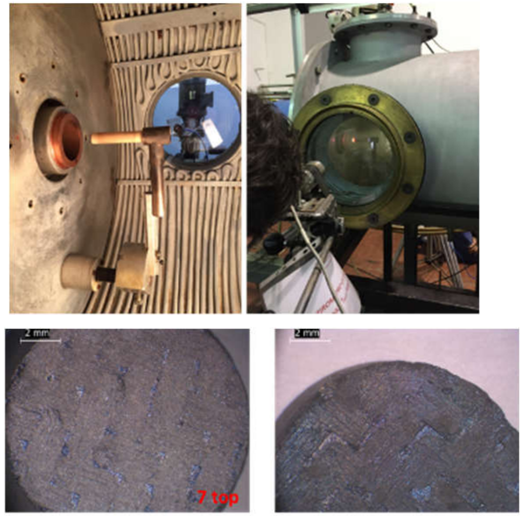
SEM- Surface



SEM - Cross section



- ❑ The coating is made by a reaction process and not a deposition one
- ❑ Coating can be easily reapplied after use (reusability).

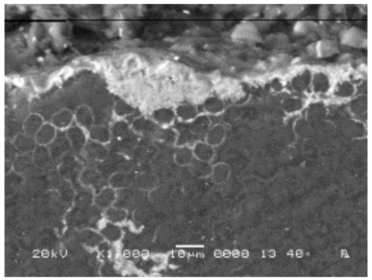


PLASMA ARC-JET TESTS

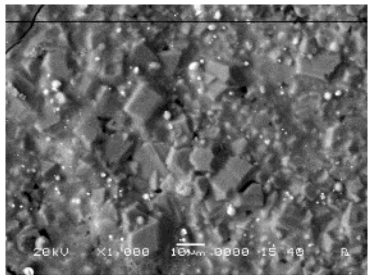
No active oxidation under relevant environmental testing carried out in plasma arc-jet facilities CIRA-GHIBLI

- Tmax = 1600°C
- P02= 2500 Pa
- Exp. time 600 s

SEM - Cross section



SEM- Surface



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The goal of this test is to assess the behavior of the CMC technological demonstrator developed in the frame of Pro.R.A. funded SHS program in representative conditions of Space Rider atmospheric re-entry.

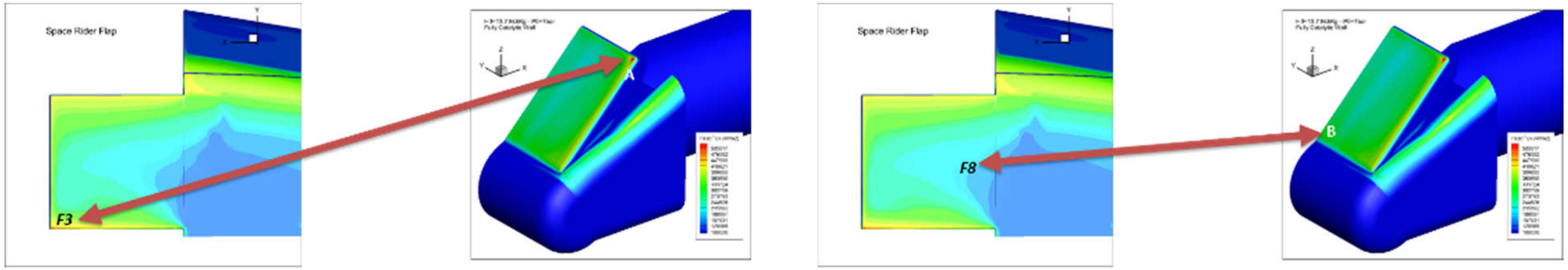
The test article has the same geometry of the EXPERT flap. This choice was driven from a twofold benefit:

- ✓ from one side the availability of the same test holder;
- ✓ from the other side to have a direct comparison in terms of aerothermal loads with a well assessed CMC technology, provided by MT-A, already tested in PWT environment.

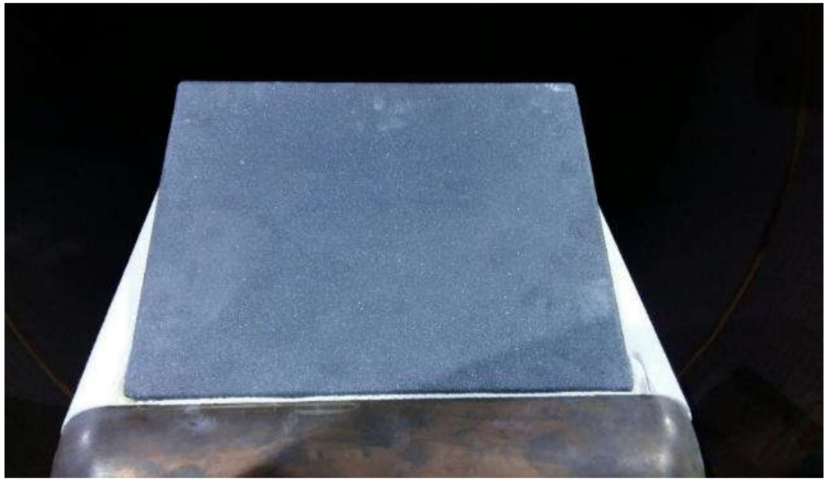
PWT TEST OBJECTIVE

Maximize the similarity with EXPERT test in order to have a direct benchmark for SHS CMC demonstrator test;

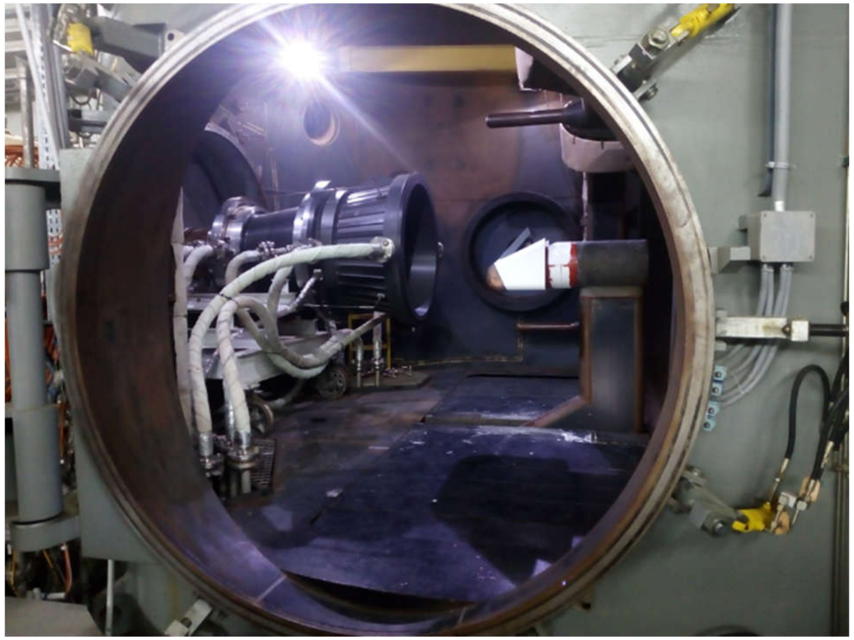
Stress the demonstrator with thermal conditions representative of the ones expected for Space Rider re-entry mission.



SR Trajectory	*SR Ref Point*	*Max heat flux*	*Max heat load*	*EXPERT Ref Point*	*EXPERT Heat Flux on ref*	*Equivalent test time*
[-]	*[-]*	*kW/m2*	*MJ/Kg*	*[-]*	*kW/m2*	*[s]*
Max Heat Flux	F3	514	264	A	500	**530**
Max Heat Load	F3	343	353	A	500	**700**
Max Heat Flux	F8	350	141	B	300	**470**
Max Heat Load	F8	176	183	B	300	**610**



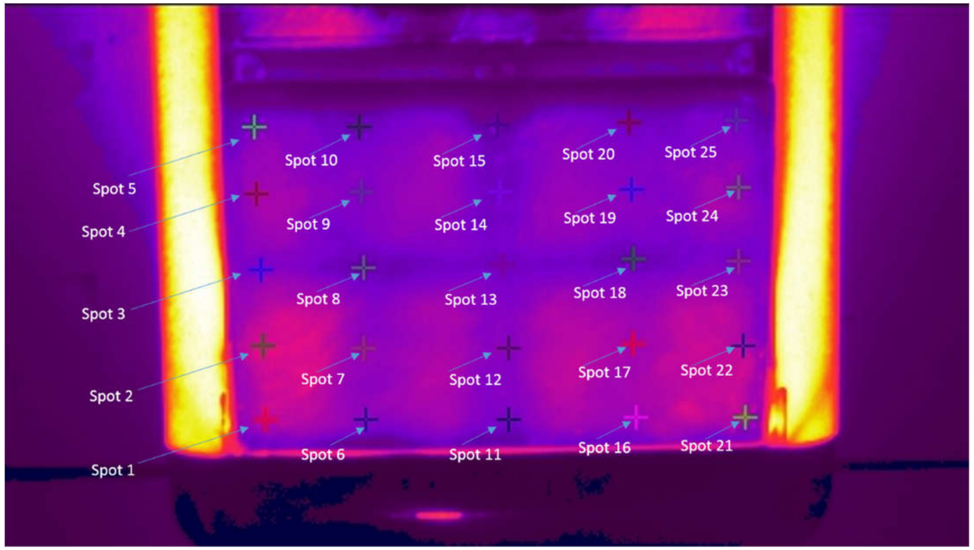
C/SiC 400mm x 300mm body flap demonstrator mounted on the Scirocco Model Holder

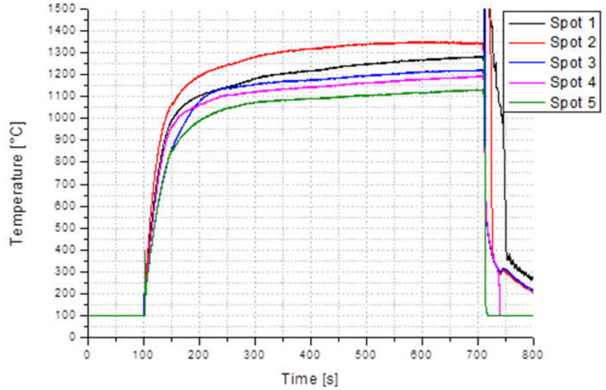


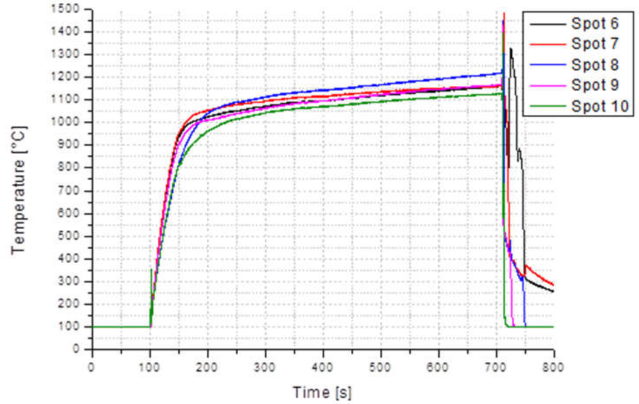
A first Plasma test in CIRA SCIROCCO facility has been performed on 18th of April on a 400 mm x 300mm reinforced flap demonstrator:

Time	*600 S*
Experienced Temperature	*1200 °C*

INFRARED MEASUREMENT

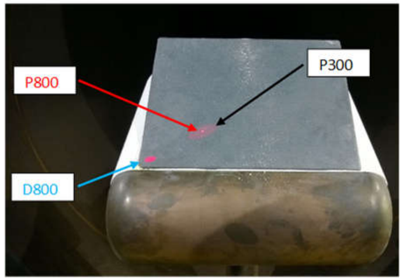


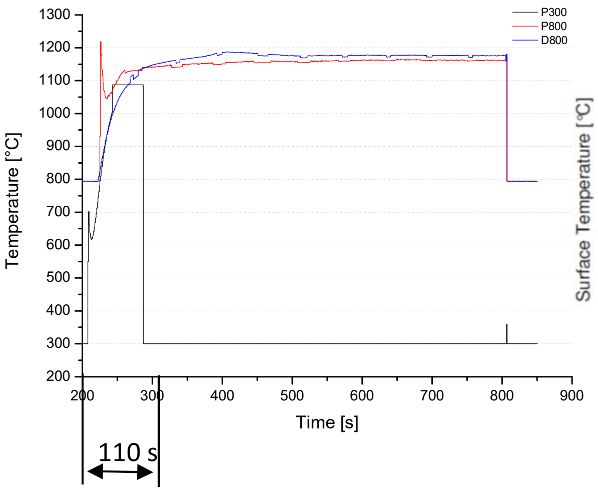




IR results require additional post processing

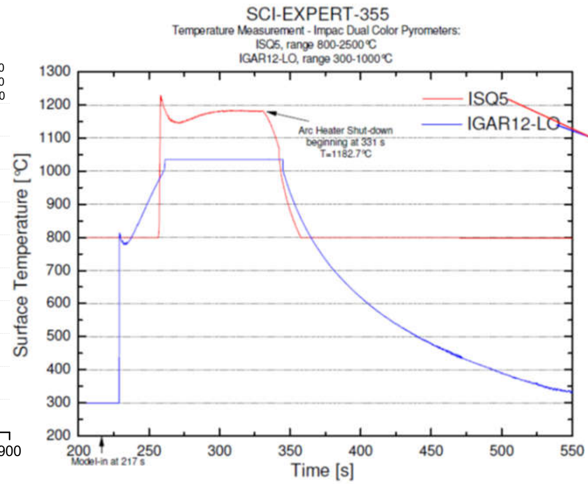
TEST SHS-SR CMC TECHNOLOGY DEMONSTRATOR, 2018

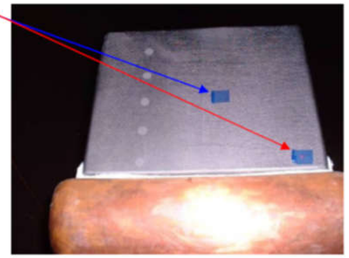


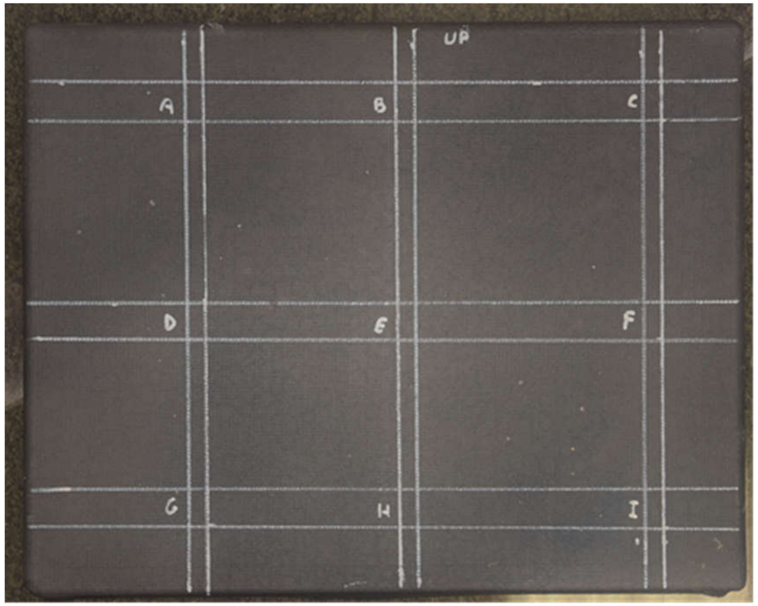


EXPERT
OFA
TEST

TEST EXPERT OPEN FLAP ASSEMBLY, 2011



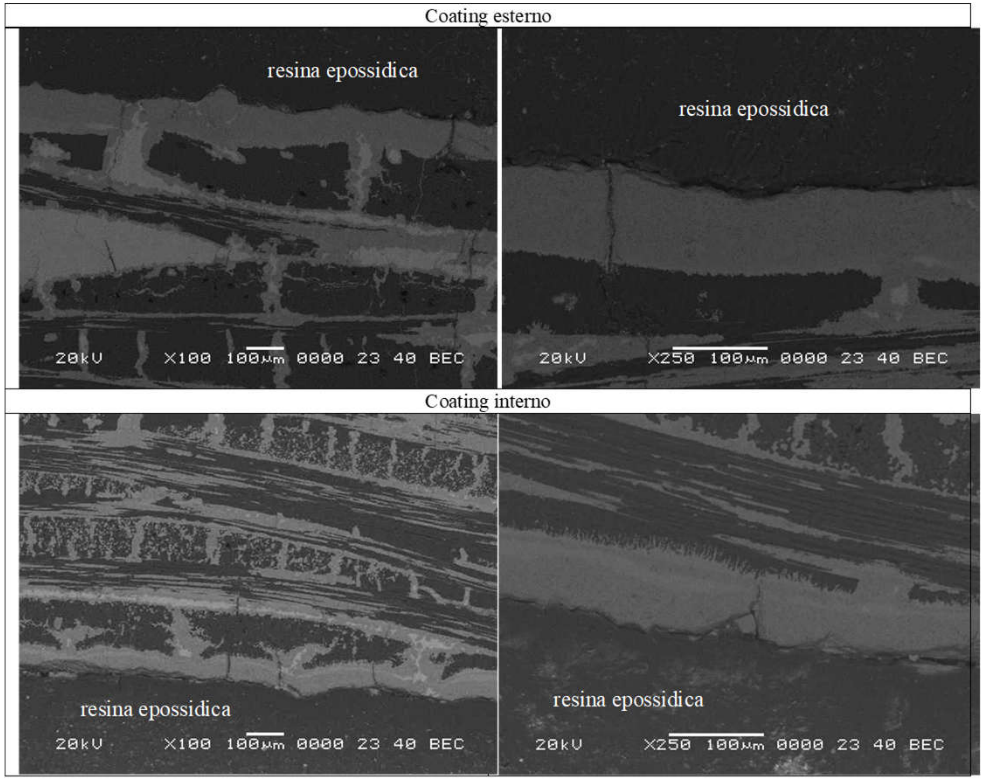




The specimens were incorporated in epoxy resin and subsequently polished with abrasive papers with decreasing FEPA granulometry (320, 500 and 1200).
The lapping and polishing process made it possible to observe the coating in section away from the area where the cut took place.
A sample was also taken from the inside, at an area with iridescent coloring. This specimen was observed on the surface as such, without performing polishing.

SEM ANALYSIS

Specimen E

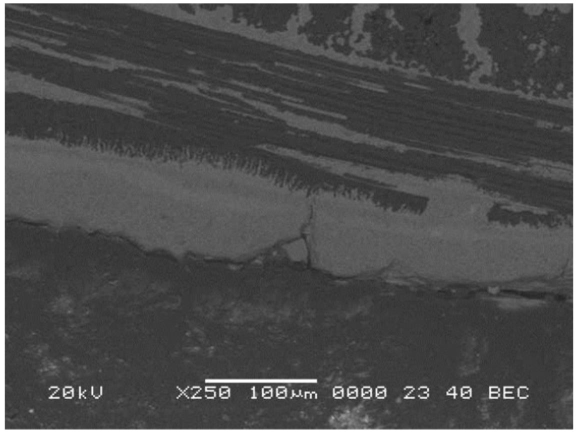


The coating on the external side appears compact and covering the entire surface. It has a high thickness, around 80-100µm. No signs of surface oxidation of the coating are observed.

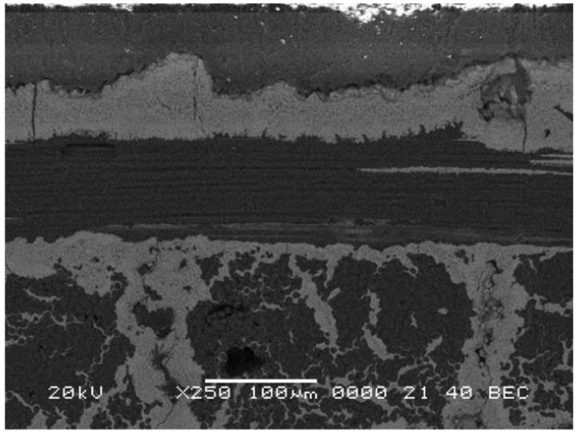
Microcracks are observed which in some cases also involve part of the CMC. In correspondence of such cracks, however, no signs of oxidation of the fibers are observed.

SEM ANALYSIS

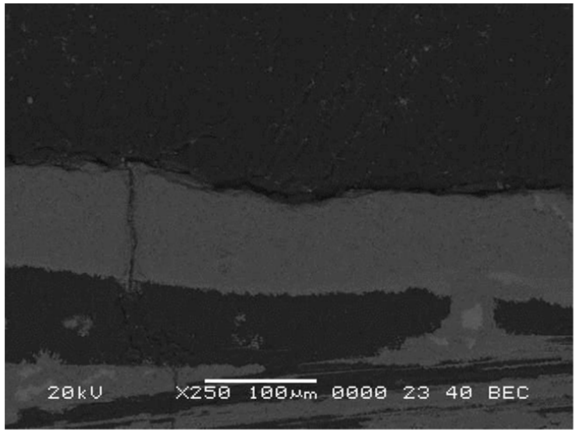
Inside



Withness coupon

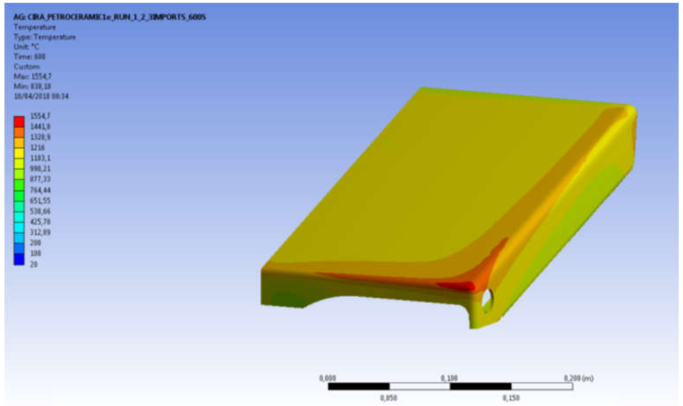


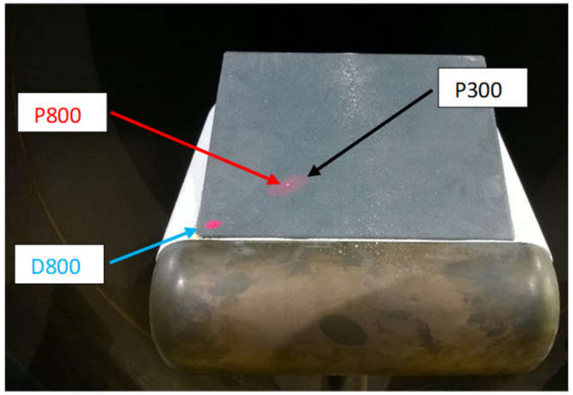
Outside

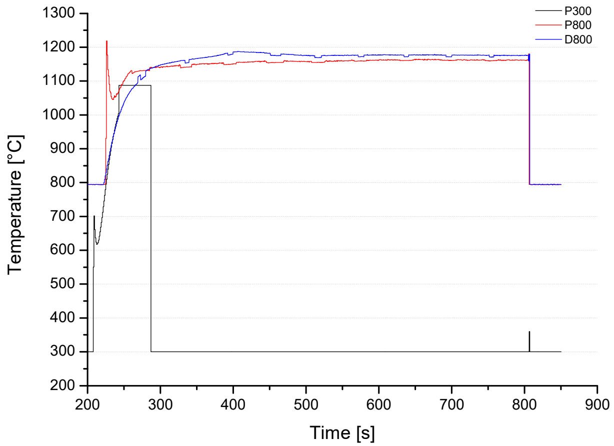


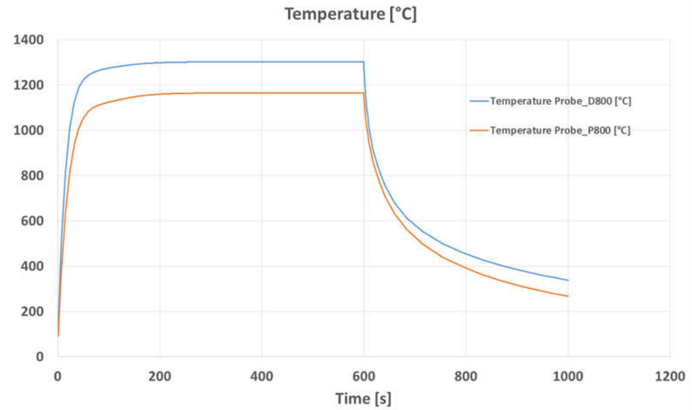
The coating is very similar to that of the reference plate, both for thickness and for compactness and extent of cracking. No signs of deterioration of coating and CMC due to the test are observed.

Numerical Model









TEST POINT SET-UP

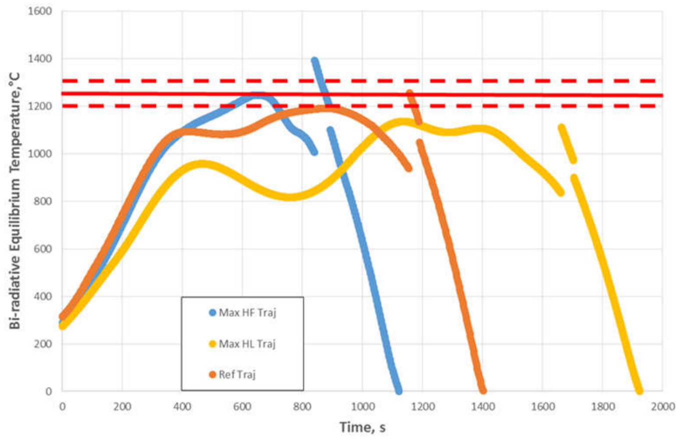
The temperature requirement has been defined by considering the bi-radiative equilibrium condition (i.e. body flap is assumed as a thin plate emitting in both windward and leeward surfaces with ε=0.8) on the GCP F3 along the reference trajectory.

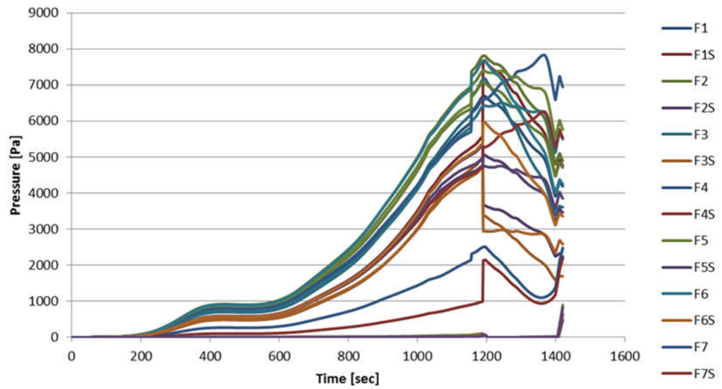
A constant temperature of 1250°C ± 50°C shall be maintained at the center of the sample.

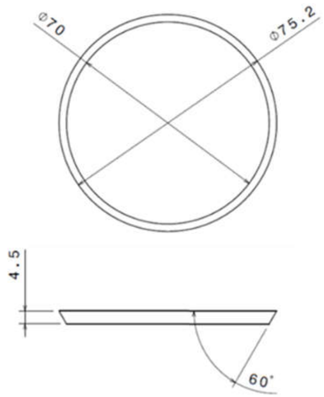
The duration of each cycle has been obtained by dividing the heat load obtained on the reference trajectory for the maximum heat flux (490 kW/m2 due to laminar-turbulent transition) of the GCP F3:

Duration = 344 Mj/m2 /490 kW/m2 = 690 s ≈ **700 s**

A constant wall pressure lower than 80 mbar shall be maintained throughout the test on the specimen wall in order to be compliant with pressure levels of flight conditions







The C/SiC materials samples are disks with 70 mm of exposed surface. They shall be slotted in the SCIROCCO Standard Model Holder.

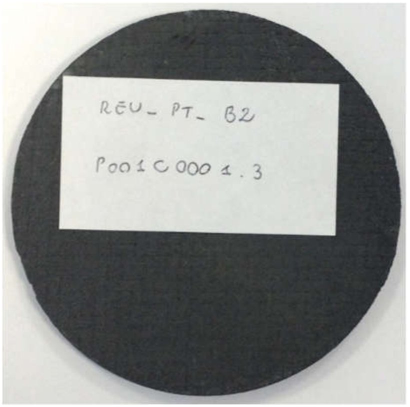
- Four samples are provided by two different process routes by application of the same process parameters in the frame of Batch#2 material characterization.
- For each process route the two samples will be used respectively as reference sample by evaluating bending strength and performing SEM analysis at the end of manufacturing process and as reusability test sample.
- The reusability sample will be exposed to aerothermal cyclic loads representatives of six re-entry flights. After tests the sample will be cut to obtain specimens for bending test strength and for SEM post-test analysis.

PWT TEST SAMPLES

Short ID:113

Front

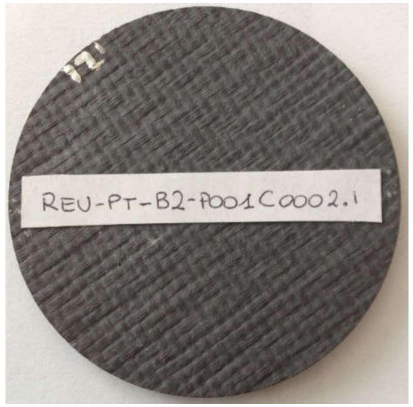
Back



Short ID:121

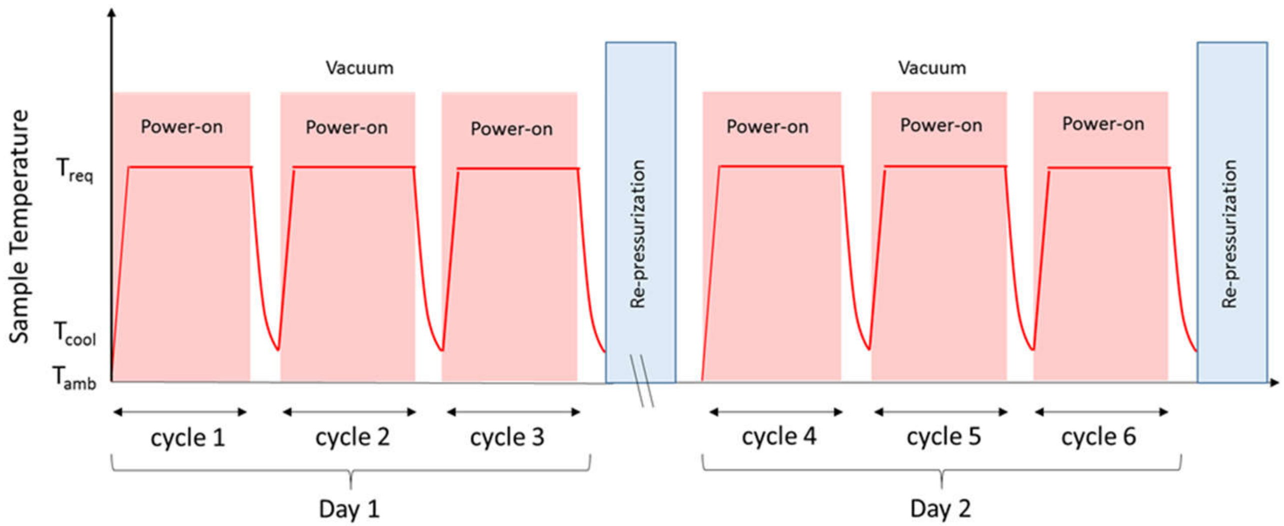
Front

Back



NOTE: Different sample colouring it’s only a picture artifact

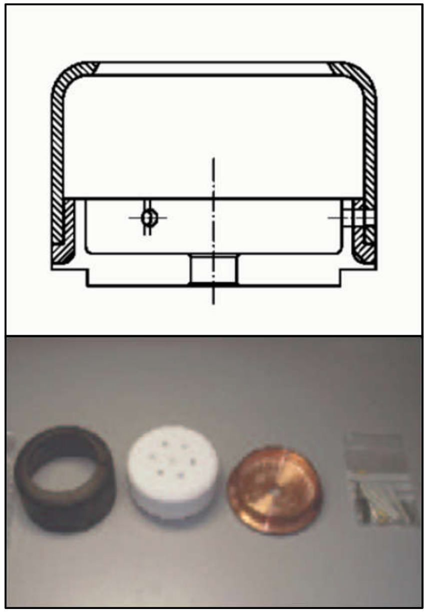
TEST MATRIX & TEST PROCEDURE



Test Campaign	Sample ID	Type of Test
1	113	PWT + Bending + SEM
2	121	PWT + Bending + SEM

Test Model & Test Set Up

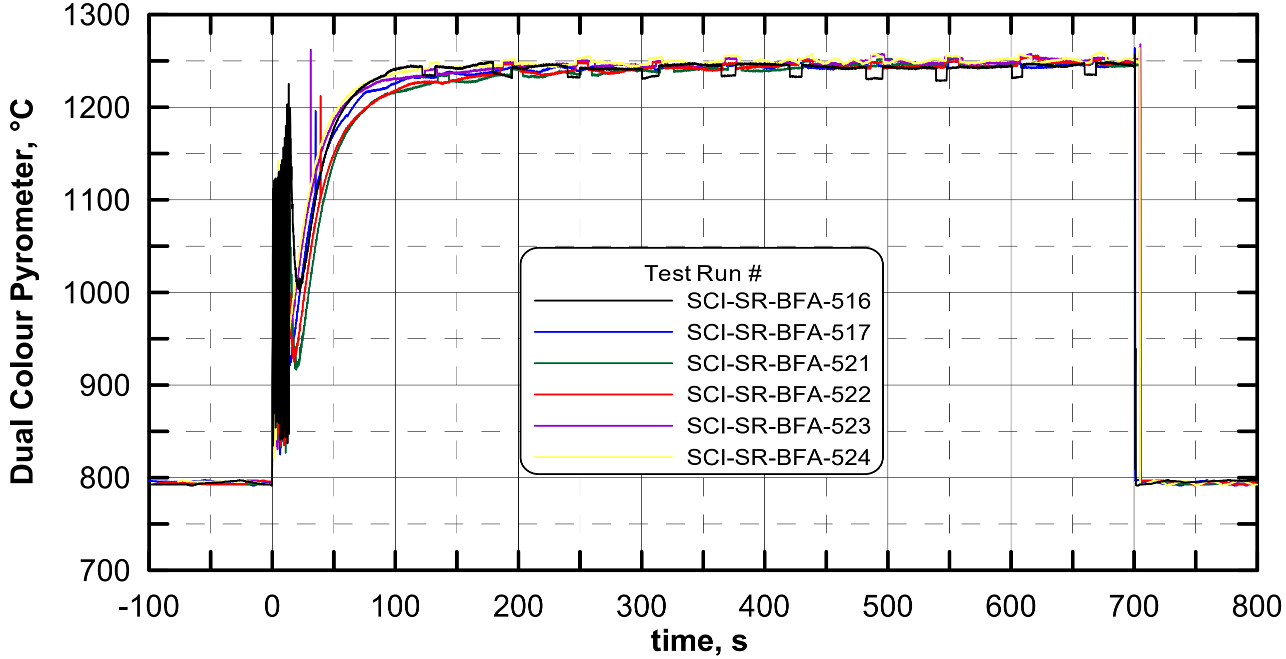
The model geometry consist in a flat faced cylinder, known as Standard Model Holder, not cooled, with the housing made of SiC and the inner made of bulk polycrystalline fibers, to be interfaced to an appropriate copper flange and then installed on the SCIROCCO cooled probe arm.



A dual color/single color 800-2500°C range is pointed on the center of the samples (left). Other two dual color/single color are pointed on the same position once the sample is out of the plasma jet to monitor the cooling phase, guaranteeing that between two cycles the sample temperature is below 400°C (right).

Tag	Manufacturer	Model	Operative Mode	Range [°C]	Wavelength [µm]
D800	DIAS	DSRF 11N	Two/Single-Color	800÷2500	0.7÷1.1
P300	IMPAC	IGAR 12-LO	Two/Single-Color	300÷1000	1.52÷1.64
P800	IMPAC	ISQ5	Two/Single-Color	800÷2500	0.9÷1.05

SUMMARY



The sample has been exposed to the equivalent re-entry environment for an overall time of **4200 (1h 10')**

TEMPERATURE HOMOGENEITY

A confirmation of the temperature uniformity all over the sample surface has been obtained by Infrared Camera measurements.

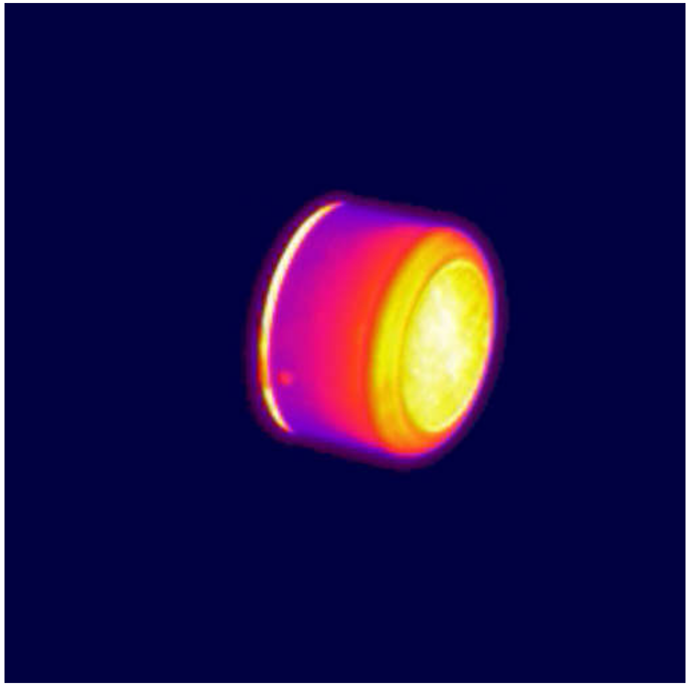
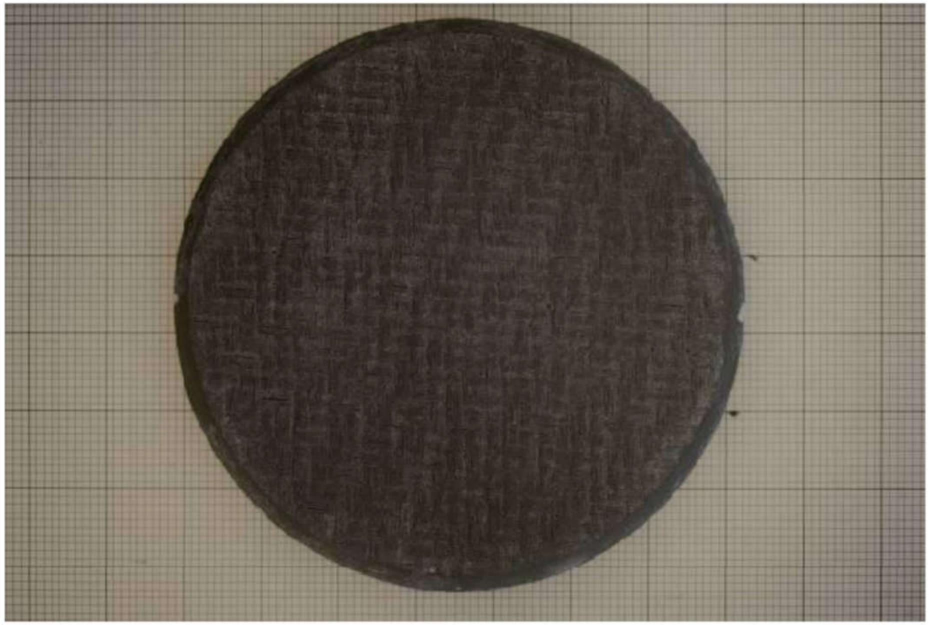


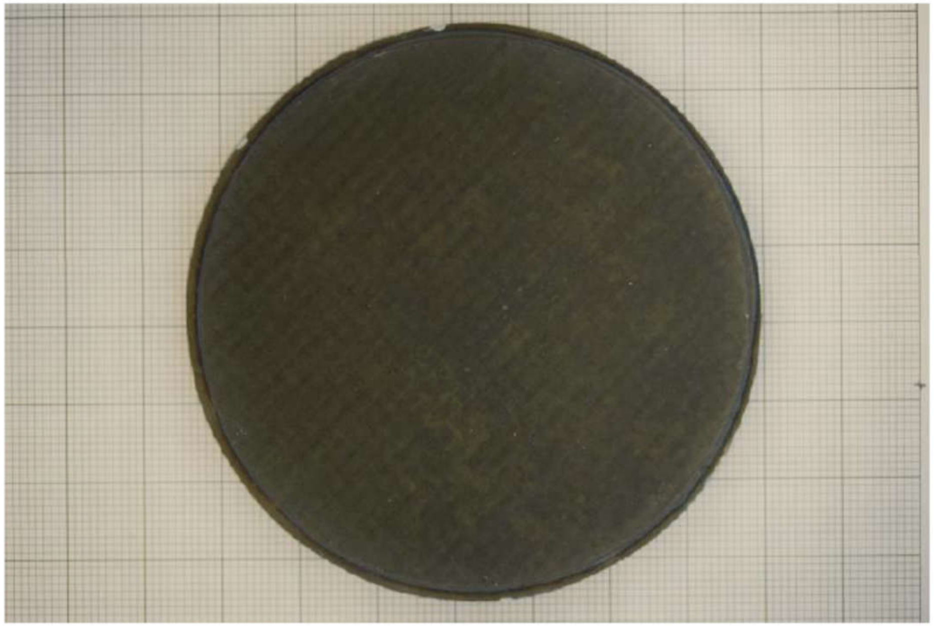
Image taken from Test Campaign #2 (raw data)

REFERENCE SAMPLES



Short ID:112

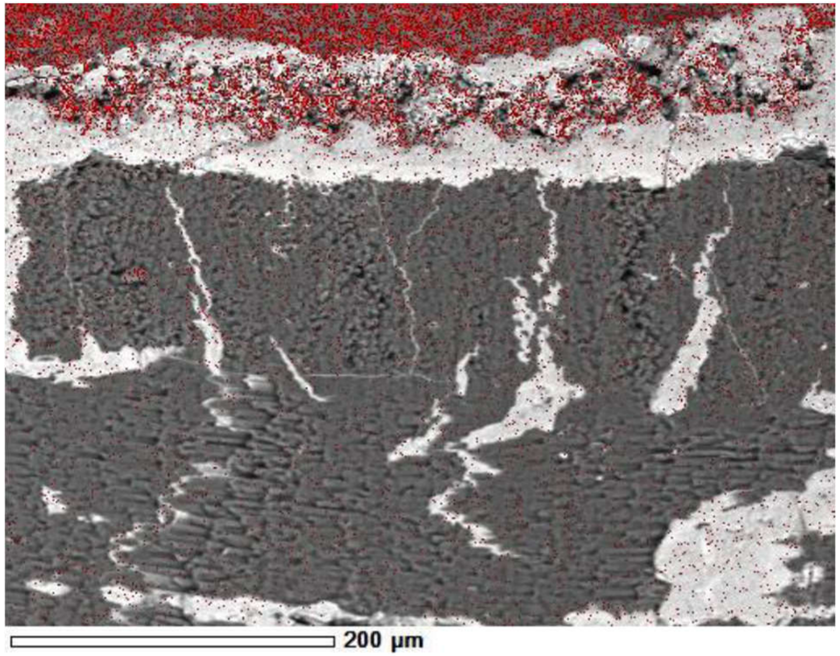
PWT TESTED SAMPLES



Short ID:113

Weight measurements were performed with ORMA BC 500 LCD (S011) (accuracy of 0.01g)
The samples were dried at 105 ° C for 2 hours before each weight measurement.
Mass loss below 0.3% has been measured.

The chemical map shows that oxidation affects only the external part of the coating.
After the 6 cycles exposure an inner layer of compact coating consisting exclusively of SiC with a thickness of about 20µm can be observed.
It is interesting to note that in the bulk of the composite no oxygen is found at SiC and free silicon.

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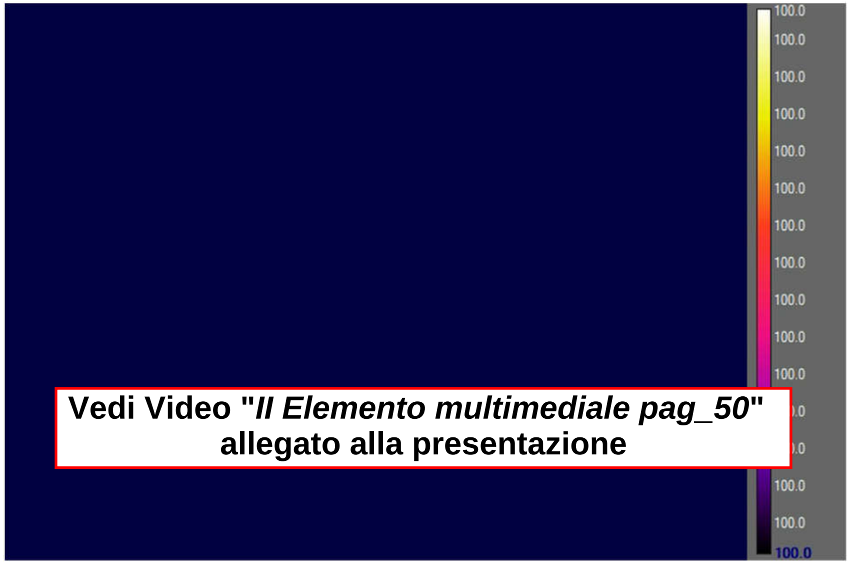
Vedi Video "*SCI-SR-BFA-516 pag_50*"
allegato alla presentazione
26-10-2018 16:05:02


Vedi Video "*Il Elemento multimediale pag_50*"
allegato alla presentazione

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