Plasma Wind Tunnel tests on flexible, foldable and inflatable structures

2nd Symposium on Hypersonic Flight

Topic: Aerodynamics and aerothermodynamics

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INTRODUCTION

Aero Sekur experience in PWT testing activities last since 2004 and is related with three programs:

IRT
SPEM
SPEM GSE

The first program was sponsored by the ESA, while the other two have been co-sponsored by Italian Air Force and Aero Sekur.

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IRT

IRT (Inflatable Re-entry Technology) was a Program sponsored by the European Space Agency in which Aero Sekur was Prime Contractor.
Objectives of the IRT program were:

- to **identify candidate materials** for use in a new generation of inflatable re-entry capsule
- to **design and manufacture a full scale model** (3m diameter) in order to develop manufacturing technologies
- to **test in PWT a scaled model** in order to verify the capability of the selected design to approach the hot phase of an orbital re-entry

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IRT (cont.)

IRT Full Scale Model

Full scale model had a cone with 60°angle and an external diameter of 3 meters, made by a truss structure supporting the TPS.
Truss structure had a single layer in Aertex as restraint for structural resistance and bladder for pneumatic retention.

Truss structure in the conical part was covered by a Kevlar layer to mechanically support the TPS in the structure free spaces

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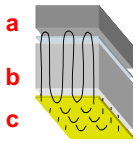
IRT (cont.)

IRT TPS

TPS was made by three layers; the two internal layers were made in Nextel and Saffil, while the external layer was in Ablative Silicon which preparation was based on an Aero Sekur specification. The function of the Ablative Silicon was clearly to absorb the heat due to atmospheric re-entry in order to protect internal structure.



a: Ablative Silicon
b: Thermal Protection (Nextel and Saffil)
c: Structural layer

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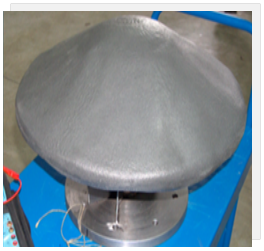
IRT (cont.)

IRT PWT

Two scaled models with a diameter of 600 mm have been tested.
In the scaled model only the Thermal Protection System, including Kevlar support, was represented.
The Test Article was supported by a metallic structure interfacing with PWT.



Before the performance of the test on the scaled model, thermal properties of TPS have been tested in a smaller PWT.
The tests were performed in CIRA PWT “Scirocco” with a peak heat flux of 700 KW/m2 and a total heat load of 60 MJ/m2
The ablative material protected the internal layers and no damage occurred to the various TPS layers.

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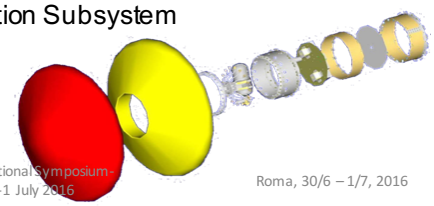
SPEM

SPEM stands for “SPacecrew Emergency Module”. The idea, presented to and approved by Italian Air Force, was to start the development of a flexible, inflatable and foldable module for emergency re-entry from orbiting Spaceships.
With a continuous interaction with IAF, AS developed a demonstrator to test the Thermal Protection in real re-entry from orbit conditions.
The capsule diameter was 1m with a mass was 15 Kg.
The capsule was made of the following subsystems:

- TPS, including ablative material developed according to Aero Sekur specification).
- Inflatable structure, including Inflation Subsystem
- Avionics
- Parachute
- Mechanical Capsule structure.



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SPEM (cont.)

SPEM PWT

Since it has not been possible to fly the capsule in a reentry mission, it was agreed with IAF to test a scaled model in the CIRA PWT “Scirocco” to validate the SPEM concept. The test was performed with a 600 mm diameter scaled model.
In this model there was an inflatable structure protected by the same TPS as in the full scale model. The inflatable structure was a single Kapton chamber protected by an external structural Kevlar layer.
Finally, there was a metallic structure interfacing the test facility.

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SPEM (cont.)

SPEM PWT (cont.)

The test was performed on September 26th, 2008. Test data were: **Heat flux**: **1240 KW/m²** and **time of exposition 108 sec**. The maximum Temperature reached on the external layer (ablative Silicone) was **1242,5°C**, while the internal temperature of the inflated chamber was lower than **40°C**.

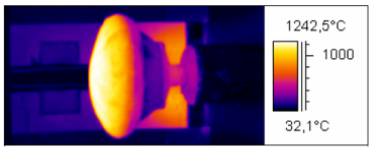
CIRA

DOCUMENT NUMBER
IDENTIFICATIVO CIRA-CF-08-1451
REV. 0

PROBE, ARC HEATER, NOZZLE AND TEST CHAMBER DATA

In Table 1 a summary of the Probe, Arc Heater, Nozzle and Test Chamber measurements is reported.

q_s [kW/m²]	P_s [mbar]	H_0 [MJ/Kg]	P_0 [bar]	m_{Air} [kg/s]	m_{Argon} [kg/s]	P_{Arc} [MW]	t_d [s]	P_{exit} [mbar]	P_{TC} [mbar]	
1240 ± 40	12.2 ± 1.1	15.9 ± 0.4	3.9 ± 0.3	0.65 ± 0.02	0,030 ± 0.003	28.4 ± 1.1	405 ± 1	0.140 ± 0.002	0.097 ± 0.002	Free jet
								0.140 ± 0.002	0.202 ± 0.001	Probe in
								0.596 ± 0.007	0.525 ± 0.003	Model in



t_f=60s

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SPEM GSE

Based on the positive and very promising results obtained with previous Programs, Italian Air Force and Aero Sekur discussed the follow-on activities.
The first issue identified was an economical issue.
The study and the experimental evaluation of aerospace materials (in particular for TPS) is actually one of the most challenging and money demanding issues in the aerospace science; in particular tests in PWT require a very high level of economical effort.
Therefore, it was agreed to perform a study to obtain a Test Facility to perform thermal tests, at least in the preliminary stages of development of the TPS materials, with economical facilities.

SPEM GSE (cont)

Italian Air Force and Aero Sekur developed a Thermometric Facility (so called SPEM GSE) to test specimens of thermal protection materials immersed inside a high speed hot gas flux ejected by aircraft turbine, having enough energy to represent the application environment

The facility is able to evaluate flux enthalpy by measuring gas speed, stagnation point and free stream temperatures as well as front and back temperatures in the specimen in order to evaluate the evolution of the thermal flux versus the time.

Finally, the Facility is able to characterize the material performance (chemical properties, physical properties, etc.).

SPEM GSE (cont.)

This thermometric facility is conceived for dual uses applications, covering either aeronautical and also specific space applications, and could potentially be used also to assess other materials performance used for aircraft support/protections.

Purpose of the SPEM GSE is by Aero Sekur to test:

- Ablative materials,
- Different thermal protections materials as those used for hot structures (combustion chambers, nozzles, thermo-structural protections for hypersonic flight).

The method is considered cooperative and complementary to the standard facilities able to represent the re-entry environment, being effective whenever a comparison in performance of different materials is needed

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SPEM GSE (cont.)

The Facility is composed by:

- Calorimeter:
  - Pitot tube,
  - Thermocouples with exposed junction and grounded junction,
  - Specimen of ablative material insulated with mullite tube;
- Calorimeter support;
- Thermistor (for temperature control of the acquisition electronics);
- Acquisition electronics;

In addition, there are several other tools, like:

- Remote control facility,
- Alignment tooling,
- High speed cameras,

Finally, IAF provided the overall Logistics Support as well as the Aircraft.

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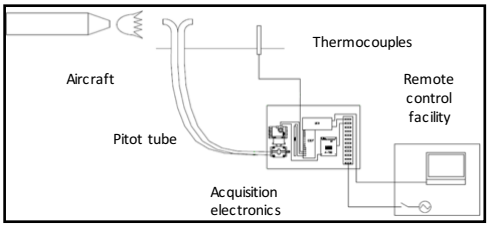
SPEM GSE (cont.)
ARCHITECTURE



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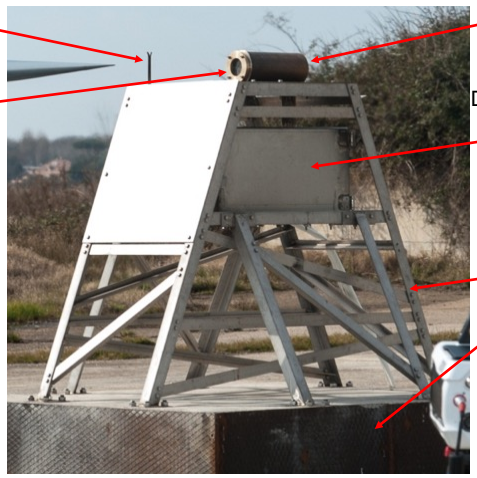
SPEM GSE (cont.)
CALORIMETER (1/2)

Pitot tube

Specimen of ablative material insulated with mullite tube

Thermocouples:
- exposed junction (for flux characterization),
- grounded junction (for specimen characterization)

Both thermocouple types are insulated by mullite tubes.



Calorimeter

Dewar box to allocate the acquisition electronics

Ground support structure

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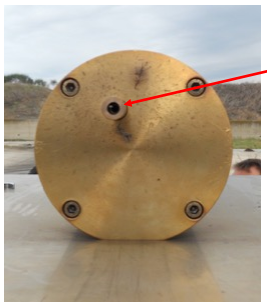
SPEM GSE (cont.)
CALORIMETER (2/2)

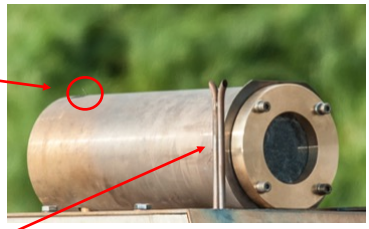
Two different configurations

Calibration set up
Dummy sample

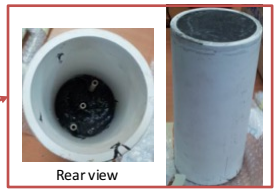


Specimen set up
Silicone elastomer ablative material

Exposed junction thermocouple (for flux characterization)



Pitot tube



Specimen with its mullite tube before insertion in calorimeter structure

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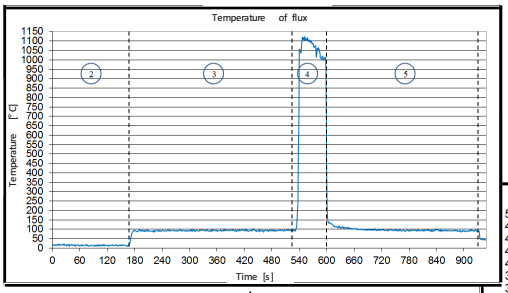
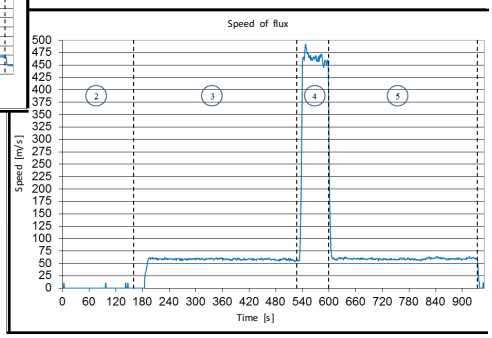
SPEM GSE (cont.)
TEST RESULTS (1/4)



4.5 meters far from the aircraft engine nozzle

Temperature of the hot gas flux

Speed of the hot gas flux



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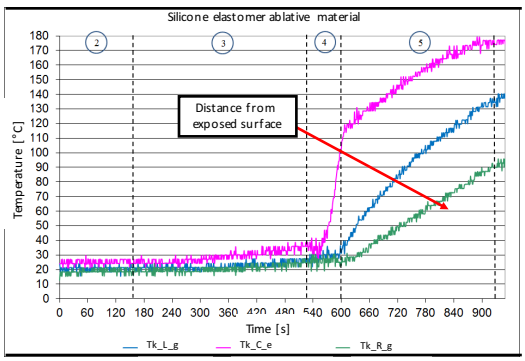
SPEM GSE (cont.)
TEST RESULTS (2/4)

Temperature in silicone elastomer ablative material measured respectively at *5 mm* (Tk_C_e), *10 mm* (Tk_L_g) and *15 mm* (Tk_R_g) from the exposed surface



Parameter	Value	
Mach number	0,6	
Flow rate	120	Kg/m^{2}s
Enthalpy	1,9	MJ/kg
Heat flux	0,5	MW/m^2

← Final values obtained

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SPEM GSE (cont.)
TEST RESULTS (3/4)

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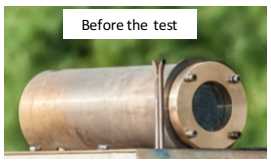
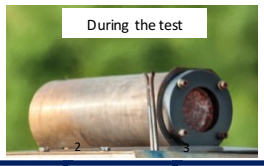
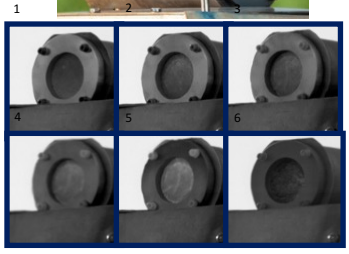
SPEM GSE (cont.)
TEST RESULTS (4/4)







High speed camera results (up to 1800 fps)

The specimen started the ablation process which extended to about 2 mm of its exposed surface

Weight before the test	0,62735 kg
Weight after the test	0,61785 kg
Delta Weight	**9,5 grams**

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SPEM GSE (cont.)
CONCLUSIONS (1/2)

Advantages

- To be able to compare ablative and thermal materials performances before deep test st o be pe rformed in a ded icated facility; this allows a reduction of cost s, enhancing the effectiveness of t he qualif ication te st programme, introducing , where necessary, a pre-qualification screening phase.
- To be quick to use, flexible, adaptable to several applications with negligible impact in the test set up configuration.
- Adaptability to different specimens sizes.
- Capability of achieving test durations of several minutes.

Drawbacks

- The representativene ss of the environment , ma inly for what the ablative materials are concerni ng, even if the enthalp ies wh ich can be achieved are sufficient to activate pyrolysis and to start ablation process.
- In particular the environment is characterized by an high gas mass rate at lo wer speed and temperature compared to the pla sma chamber.
- Additional heat flux due to molecular recombination cannot be reproduced.

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SPEM GSE (cont.)
CONCLUSIONS (2/2)

- The thermometric facility (SPEM Ground Support Equipment – SPEM GSE) designed is able to test specimens of thermal protection materials immersed inside an high speed hot gas flux ejected by aircraft turbine.
- Values of temperature, speed, enthalpy and heat flux reached during the test are sufficient for comparison in performance of different materials.
- Screening of different materials is useful and costs saving before deep tests in dedicated facility.
- The facility could be improved and easily adapted for different needs and configurations (materials tests, full scale and scaled models/systems tests, aircraft engine heat flux characterization, …).
- The facility could be useful for mechanical test of the inflated/deployed reentry systems.
- The facility is conceived to be used for dual uses applications, covering either institutional aeronautical and also specific space applications.


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