

Che c'è di NUOVO?

THE ITALIAN CONTRIBUTION TO SPACE RESEARCH AND DEVELOPMENT HAS MULTIPLIED EVERY YEAR, PARTICULARLY FOR MATERIAL STUDIES MADE INTO RE-ENTRY AND HYPERSONIC FLIGHT



“The challenge to build new thermostructures able to survive in extreme conditions was raised in 2002”

BY GENNARO RUSSO & MARIA PIA AMELIO

The first workshop on the Science and Technology of Ultra-High Temperature Ceramic-based (UHTC) thermostructures, organized by Italian Aerospace Research Center CIRA in October 2008, brought together the entire Italian scientific and entrepreneurial community to assess its achievements across the field of hypersonic flight and space technologies, and the new and relevant role the country has taken at European level.

The conference, which included representatives from European and US space agencies ESA and NASA, confirmed the high technological level achieved by Italian space research, legitimizing the country's ambition to play a major role in future international programs aimed at the development of new aerospace transport systems. The ambition is targeted directly at speeding up the transportation of goods and passengers (Rome to Tokyo in two to four hours) and to make space flight more and more like today's civil aviation.

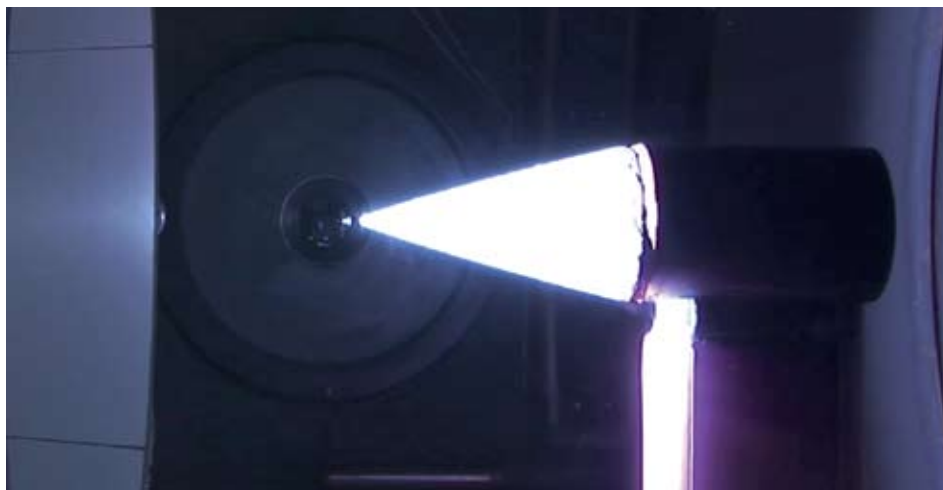
UHTC material-based thermostructures is a niche in which a high level of technological maturity and competence has been achieved. A good example of this is the innovative test and development of the unmanned space vehicle (USV) nose-cone prototype and the wing leading edge, which are the most critical parts of a hyperfast aircraft as these structures

are subjected to extremely high thermal flows and temperatures.

The challenge to build new thermostructures able to survive in extreme conditions was raised by CIRA in 2002 with the USV program and, more specifically, within the USV-TECH Sharp Hot Structures (SHS) project. The adoption of aerodynamic and sharp shapes allows greater maneuverability and a reduction in aerodynamic drag when compared to the 'blunt body' of the Shuttle. But these advantages have to be balanced against a considerable worsening of the operational conditions of materials and structures in terms of temperature and heat flow, which could even affect the capability of the aircraft to survive this extreme environment.

With the development of the SHS project, various models of a spacecraft nose cone that became progressively more advanced were successfully built and tested in CIRA's 'Scirocco' plasma wind tunnel. The last model, which had a particularly sharp profile characterized by a 10mm radius of curvature, was made up of a C/SiC-based dome and a massive ZrB₂/SiC tip.

The test article has now been tested twice in the plasma wind tunnel after substantial improvements, especially to the ceramic tip's mechanical interface. The tests were designed according to the requirements defined for the suborbital re-entry mission of the USV



Ultra-high temperature test in the Scirocco Plasma Wind Tunnel of the nose cap model for the new generation of space vehicles

Flight expert

The European Experimental Re-entry Test-bed (EXPERT) vehicle represents major ongoing development. Its results may benefit future scientific missions to planets with an atmosphere and future reusable launcher programs.

The objective of EXPERT is to provide a testbed for the validation of aerothermodynamics models, codes, and ground test facilities in a representative flight environment, to improve the understanding of issues related to analysis, testing, and extrapolation to flight. The vehicle will be launched on a suborbital trajectory using a Volna missile.

program. During the first test, the model was subjected to a thermal flow of around $1.8\text{MW}/\text{m}^2$ for 72 seconds, and in the second test to a much greater thermal flow, $3\text{MW}/\text{m}^2$ for 108 seconds (the Shuttle resists up to $800\text{kW}/\text{m}^2$). The facility was operating at a power of 14MW and a total enthalpy of $13.6\text{MJ}/\text{kg}$, bringing the tip of the nose to temperatures higher than $1,800^\circ\text{C}$ (the Shuttle doesn't exceed $1,600^\circ\text{C}$).

This careful check showed that, despite slight damage occurring during the first seconds of testing, the model was able to withstand the intense thermal stress without any major failure, and was also able to withstand the delicate re-entry into the atmosphere.

A third test was carried out in January 2009, pushing the installation to the limits of its operating envelope. The nose cone was to be taken to its limits of theoretical resistance capabilities, with exposure to around $4.5\text{MW}/\text{m}^2$, corresponding to a forecast maximum temperature at stagnation point of over $2,000^\circ\text{C}$. The test was interrupted because of technical problems, but will be repeated over the coming months.

Other components constructed under the guidance of CIRA passed the tests carried out in the Scirocco. These were the components that, in the near future, will be used in the European Space Agency's EXPERT ballistic capsule (maiden flight set for 2010, at a speed of $5\text{km}/\text{s}$), and the IXV lifting capsule (maiden flight in 2012, at a speed of $7\text{km}/\text{s}$). They will

“The tips of the winglets will be exposed to a thermal flow of around $5\text{MW}/\text{m}^2$, bringing the UHTC material to about $2,000^\circ\text{C}$ ”



Configuration of the two EXPERT winglet models

First configuration of the wing model fitted with an actively refrigerated metal leading edge and carbon-carbon panels



therefore be tested under real flight and atmospheric re-entry conditions.

The prime components were small aerodynamic surfaces called winglets, which will be positioned on the outside of the capsule on two of the truncated cone surfaces opposite each other, to check resistance during re-entry from an altitude of 120km. During this phase, the tips of the winglets will be exposed to a thermal flow of around $5\text{MW}/\text{m}^2$, bringing the UHTC material to about $2,000^\circ\text{C}$.

During 2008, two models of this payload were built, and they have already passed the mechanical and thermostructural qualification campaign according to ESA requirements. During the mechanical tests carried out at CIRA's Smart Structures Laboratory, the winglets were loaded up to a limit of twice the maximum stress foreseen during the launch phase. The

analyses and inspections carried out before and after the test demonstrated their compliance with the requirements, sustaining the test loads without suffering any damage. The test carried out in the Scirocco plasma wind tunnel, where the winglets were exposed to the same thermal flows they will support during the re-entry from space, was also positive.

Another example of research activities conducted by an all-Italian team is represented by the Advanced Structural Assembly (ASA) program, which is promoted and financed by the Italian Space Agency and aims to design and produce innovative materials and structural components for atmospheric re-entry and for hypersonic flight.

Three years of intense technical-scientific activity undertaken by Thales Alenia Space Italia as team leader, La Sapienza University of

Rome, and by research centers such as CIRA and CSM, supported by a number of SMEs and other universities, have produced some excellent results. A technological demonstrator of a wing segment (selected from the FTB-X unmanned spacecraft of the USV program), in full scale and complete with all the systems (electric, fluid, thermal, and structural), was realized by assembling the individual prototypes built. This demonstrator was subjected, in two different configurations, to qualification tests in the Scirocco plasma wind tunnel. Technically, the system tests carried out are among the most complex ever undertaken in Europe.

The first test concerned a wing model fitted with an actively refrigerated metal leading edge and carbon-carbon panels joined to an internal structure, with strain controlled by a system of tungsten elements coated with ceramic material. The architecture of the system was conceived in order to make integration and maintenance operations quite easy, a very important property due to its possible application in hypersonic aircraft, or reusable re-entry space vehicles.

As required during the 15 minutes of testing, a thermal flow at a stagnation point of $410\text{kW}/\text{m}^2$ was obtained, and data was measured and acquired pertaining to the temperatures achieved and the strains of the test article. The data analysis showed that the active cooling of the leading edge was able to maintain the temperature of the component under 100°C , while the passive carbon-carbon panels reached a temperature of more than 800°C .

In the second test, this time with a UHTC leading edge installed, the team had to recreate extreme thermal flow and surface temperature conditions. The test was interrupted, however, when the component failed.

A third test will be performed on a model fitted with a refrigerated metal leading edge, but one equipped with a double system of panels (the windward one in carbon-carbon and the leeward one in metal matrix composite). The test condition for this experiment is $600\text{kW}/\text{m}^2$ for 20 minutes – a higher heat flow for some more exposure time than the previous tests, to reproduce the safety re-entry conditions of the USV FTB-X aircraft.

Last but not least is the Inflatable Heat Shield, a unique thermal protection system created by Aerosekur, an Italian SME, as part of the SPEM (Spacecrew Emergency Module) project, financed by the Italian Ministry of Defense. Designed as an emergency re-entry system for astronauts in orbit, or to bring samples from space back to the earth, the inflatable heat shield consists of a flexible structure inflated with air and coated with a passive-type (without cooled parts) ablative thermal protection system. The model, measuring 600mm in diameter, was tested in the PWT and exposed to a thermal flow of $430\text{kW}/\text{m}^2$ for about 100 seconds. The positive result demonstrates that this specific Italian technology is quite close to maturity. ■

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