

Abstract Book & Final Programme

***6th European Workshop on
Thermal Protection Systems and
Hot Structures***

1 - 3 April 2009

Stuttgart, Germany

Table of Contents

Organising Committee	5
Programme	7
Abstracts	11

Organising Committee

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G. Herdrich - IRS, University of Stuttgart
H. Hald - DLR Stuttgart
H. Weihs - DLR Stuttgart
M. Klein - ESA/ESTEC/Thermal and Structures Division
H. Ritter - ESA/ESTEC/Thermal & Environmental Control Section
D. Jaredson - ESA/ESTEC/Structures Section

6th European Workshop on Thermal Protection Systems and Hot Structures

Stuttgart, 1 - 3 April 2009

Wednesday, 1 April 2009

Wednesday, April 1st 2009 - DLR Grosser Hörsaal		Page
08:30	Registration	
Opening Session Part 1		
Chair: H. Welhs (DLR), G. Herdrich (IRS), H. Ritter (ESA-ESTEC)		
9:10 - 11:00	Welcome by ESA & IRS; S. Stavriniadis & tbd	
09:30	Return, TPS and Hot Structure Technologies at DLR; L. Fröbel, DLR	
10:00	The IXV Programme - ESA's Atmospheric Re-Entry Technology Demonstrator; G. Tumino, ESA-HQ	11
10:30	EXPERT - A European Aerothermodynamics In-Flight Testbed; J. Gavira, ESA-ESTEC	11
11:00 - 11:30 Coffee break (in front of Grosser Hörsaal)		
Opening Session Part 2		
Chair: H. Welhs (DLR), G. Herdrich (IRS), H. Ritter (ESA-ESTEC)		
11:30	Thermal Protection System (TPS) and Hot Structures Activity within the FLPP Core Technology Project; J. Persson & D. Jaredson, ESA-ESTEC	11
12:00	Experimental and Numerical Entry Simulation at IRS; G. Herdrich, Institut für Raumfahrtssysteme (IRS)	11
12:30	Plasma Power Handling in the ITER Fusion Device; G. Federici, Fusion for Energy	12
13:00 - 14:15 Lunch break (at IRS building 31)		
Wednesday, April 1st 2009 - IRS Room V27.01		
Session 3A: The Intermediate eXperimental Vehicle (IXV)		
Chair: S. Langlois (ESA-ESTEC)		
14:15 - 16:15	The Intermediate eXperimental Vehicle (IXV): The European Flight Opportunity for TPS&HS Technologies; S.Langlois, ESA-ESTEC	12
14:15	TPS & HS Subsystem Activities for IXV PDR Preparation M.T. Signorelli, Thales Alenia Space	13
14:45	Thermo-Mechanical Design of the IXV Nose Assembly R. Knoche, ASTRION Space Transportation	13
Session 3B: Plasma Testing - Campaigns and Capabilities		
Chair: S. Loehle (IRS)		
14:15 - 16:15	Thermal Non-Equilibrium in the Boundary Layer of a Flat Plate in RF Air Plasma P. Boubert, CORIA	13
14:45	ASA - A System Devoted to Hypersonic-Related Technologies F. Fossati, Thales Alenia Space	14
15:15	On-going Capabilities and Developments of Re-Entry Plasma Ground Tests in EADS-Astrium B. van Ootegem, ASTRION	14
15:45 - 16:15 Coffee break (Foyer between workshop rooms)		
Session 4A: TPS Technologies - Part 1		
Chair: H. Hald (DLR), B. Behrens (EADS-Astrium)		
16:15 - 18:30	Thermal Protection Systems Portfolio of ASTRION GmbH - Recent Developments W.P.P. Fischer, ASTRION Space Transportation	14
16:15	CMC Thermal Protection System Pre-Development for Re-Entry Demonstrator Vehicles T. Pichon, SNECMA Propulsion Solide	14
17:15	Investigations of Passive to Active Oxidation on C/SiC Hot Structures F. Infeld, MT Aerospace	14
17:45	TPS Joining Technologies J. Marcos, Fundacion IVA-SMET	15
Session 4B: In-flight Measurement Systems and Observations		
Chair: G. Herdrich (IRS), A. del Vecchio (CIRA)		
16:15 - 18:30	Development and Verification of an Instrumented Aerothermal Thermal Protection System Heat Shield Plug for Flight on the Mars Science Laboratory; E. Martinez, NASA	15
16:45	Advanced Heat Flux Measurement during Re-entry Flight using The Non-Integer System Identification (NIS) Procedure, S. Lohle, University of Stuttgart	15
17:15	DEDALO: Thermo-Mechanical Monitoring by Fiber Optic Devices on UHTC Structures V. Latini, S.A.B. Aerospace	16
17:45	Airborne Re-Entry Observation Experiment SLIT: UV Spectroscopy During Stardust and ATV Re-entry; S. Lohle, IRS	16
18:30 - 20:00 Welcome drink sponsored by DLR (Foyer between workshop rooms)		

6th European Workshop on Thermal Protection Systems and Hot Structures

Stuttgart, 1 - 3 April 2009

Thursday, 2 April 2009

Thursday, April 2nd 2009 - IRS Room V27.01		Page	Thursday, April 2nd 2009 - IRS Room V27.02	Page
9:00 - 10:30	<p>Session 5A: The Sharp Edge Flight Experiment II (SHEFEX II) - Part 1</p> <p><i>Chair: H. Weihs (DLR)</i></p> <p>The Sharp Edge Flight Experiment SHEFEX II, a Status Report H. Weihs, DLR</p> <p>Design and Thermo-Mechanical Analysis of the Aerodynamic Control Surfaces on SHEFEX-II H. Eisäber, Institute of Structures and Design</p> <p>SHEFEX II Flight Instrumentation T. Thiele, DLR</p>	16 17 17	<p>Session 5B: High-Temperature Thermal Conductivity Measurements</p> <p><i>Chair: K. Keller</i></p> <p>Thermal Conductivity Measurements under Non-Standard Conditions S. Vidi, Bavarian Centre for Aerospace Research</p> <p>High Temperature Thermal Conductivity Measurement Apparatus M. Selzer, DLR</p> <p>The Use of Flash Methods to Determine Thermal Conductivity W. Hohenauer, Austrian Institute of Technology</p>	17 17 17
10:30 - 11:00 Coffee break (Foyer between workshop rooms)				
11:00 - 13:00	<p>Session 6A: The EXPERT Vehicle - Part 1</p> <p><i>Chair: A. Thirkettle (ESA-ESTEC), A. Gulhan (DLR)</i></p> <p>TPS Design Methodology for the EXPERT Capsule J. Thoemel, ESA-ESTEC</p> <p>TPS Design, Development and Verification Approach for EXPERT Program E. Brach Prever, Thales Alenia Space</p> <p>Thermal-Structural Performances of the EXPERT Thermal Protection System J. Fatemi, Dutch Space</p> <p>Thermo-Mechanical Design of The Expert Nose and Testing of The Load Introductions T. Reimer, DLR</p>	18 18 18 19	<p>Session 6B: Ablative Materials - Development and Characterisation</p> <p><i>Chair: J-M. Bouilly (EADS), L. Marraffa (ESA-ESTEC)</i></p> <p>Development of a European Ablative Material for Heatshields of Sample Return Missions H. Ritter, ESA-ESTEC</p> <p>Enhanced Ablative TPS Study for High-Energy Entry Missions F. Fossati, Thales Alenia Space</p> <p>Mechanical and Ablative Properties of Silica-Phenolic Composites for Thermal Protection Systems; M.L. Gregori, Inst. Of Aeronautics and Space</p> <p>Estimating Properties of Materials Interacted with High-Enthalpy Gas Flow by Inverse Problems Technique; A.V. Nenarokomov, Moscow Aviation Institute</p>	19 19 19 19
13:00 - 14:15 Lunch break (at IRS building 31)				
13:00 - 16:15	<p>Session 7A: The EXPERT Vehicle - Part 2</p> <p><i>Chair: F. Ratti (ESA-ESTEC), E. Brach-Prever (TAS-I)</i></p> <p>Status of the IRS EXPERT Instrumentations PYREX, PHLUX and RESPECT G. Herdrich, University of Stuttgart</p> <p>EXPERT Open Flap Assembly and its Instrumentation A. Gulhan, DLR</p> <p>Thermal Measurement Techniques for Movable Control Surfaces in Re-entry Vehicles C. Pereira, RUAG Aerospace Wallisellen</p> <p>Qualification of a Ceramic Fin for Flight on European Experimental re-entering Capsule EXPERT; A. Del Vecchio, CIRA</p>	20 20 21 22	<p>Session 7B: Numerical Modelling of Ablation Processes</p> <p><i>Chair: J. Beck (FGE), M. Fertig (IRS)</i></p> <p>Ablation Response of Fibrous Materials with Different Matrices: Modeling, Comparison, and Application; J. Lachaud, NASA Ames Research Center</p> <p>Design and Numerical Modelling of Charring Ablators for Re-Entry Applications T. van Eekelen, SAMTECH SA</p> <p>Navier-Stokes Simulations with Graphite Surface Ablation for Atmospheric Entry D. Bianchi, La Sapienza University, Rome</p> <p>Numerical Rebuilding of Ablative Test Cases Using KCMA Ph. Reynier, ISA</p>	22 22 22 23
16:30 Bus transfer to Ludwigsburg (leaving from IRS)				
17:30 - 22:00 Visit Schloss Ludwigsburg and Workshop dinner				

6th European Workshop on Thermal Protection Systems and Hot Structures

Stuttgart, 1 - 3 April 2009

Friday, 3 April 2009

Friday, April 3rd 2009 - IRS Room V27.01		Page	Friday, April 3rd 2009 - IRS Room V27.02	Page
9:00 - 10:30	<p>Session 8A: The Sharp Edge Flight Experiment II (SHEFEX II) - Part 2</p> <p style="text-align: center;">Chair: H. Weihs (DLR), A. Catolino (NASA Glenn)</p> <p>ASTRIUM's TPS Experiments on SHEFEX II - Design & Analyses W.P.P. Fischer, ASTRIUM GmbH</p> <p>Design and Layout of the Combined Sensor System COMPARE for SHEFEX II A. Preci, Univ. of Stuttgart</p> <p>Heat Balance of the Transpiration-Cooled Heat Shield Experiment AKTV on SHEFEX II H. Boehrk, DLR</p>	23	<p>Session 8B: Component Testing</p> <p>Upgrade of Three Laboratory Test Setups to Measure Material Properties and Antenna Models at High Temperatures occurring during Re-entry Vehicle Flights P. Kabacik, Wroclaw University of Technology</p> <p>Computed Tomography for Non-Destructive Inspection of TPS Components T. Ullmann, DLR</p> <p>(no presentation foreseen)</p>	24 25
Coffee break (Foyer between workshop rooms)				
10:30 - 11:00				
11:00 - 13:00	<p>Session 9A: TPS Technologies - Part 2 (Concepts and Modelling)</p> <p style="text-align: center;">Chair: D. Jaredson (ESA-ESTEC)</p> <p>Film Cooling Investigation of a Double Wedge Model in Hypersonic Flow K.A. Heufer, RWTH</p> <p>UHTC Thermal Sprayed Coating as a TPS for Re-Entry Vehicles M. Tului, Centro Sviluppo Materiali S.p.A.</p> <p>Analysis and Design of UHTC Hot Structures for Ground and Flight Tests M. De Stefano Fumo, University of Naples</p> <p>Modeling Elastic and Thermal Properties of 2.5D Carbon Fiber C/SiC Hybrid Matrix Composites by Homogenization Method; L. Parrini, CTA-IAE</p>	25	<p>Session 9B: Atmospheric Entry at Mars</p> <p style="text-align: center;">Chair: P. Omary (CNES), I. Montois (CEA)</p> <p>Computational Aeroheating Analyses of a Capsule in Martian Atmosphere G. Pezzella, CIRA</p> <p>Thermal Protection System of the ExoMars Entry Probe J-M. Bouilly, EADS ASTRIUM Space Transportation</p> <p>Particle Erosion Tests on an Ablative Material in Martian Atmosphere B. Esser, DLR</p> <p>Dust Particle Erosion during Mars Entry K. Keller, HPS GmbH</p>	26 27 27
13:20 - 14:00	Visits of Institutes at DLR & IRS			

Abstracts

The IXV Programme Esa's Atmospheric Re-Entry Technology Demonstrator

*Giorgio, Tumino
ESA-HQ*

Since 2000, ESA has focused on an optimized long-term European roadmap for in-flight experimentation of atmospheric re-entry enabling systems and technologies. In 2005, further consolidation with Industry confirmed the Intermediate eXperimental Vehicle (IXV) project as the next core step of such European experimentation effort. The IXV project builds on previous European achievements at the system and technology levels, brings significant advancements with respect to previous European flying test-beds, and provides an affordable and concrete mean to consolidate Europe's autonomous position in the strategic field of atmospheric re-entry for future ambitious space transportation applications. The IXV key mission and system objectives are the design, development, manufacturing, assembling and on-ground to in-flight verification of an autonomous European lifting and aerodynamically controlled atmospheric re-entry system, integrating the critical re-entry technologies at the system level. Among such critical technologies of interest, special attention is paid to:

- several thermal protections and hot structures solutions,
- advanced instrumentation for aerodynamics and aethermodynamics,
- guidance, navigation and flight control through combined jets and aerodynamic flaps. The IXV design activities are well in progress entering the full development (i.e. phase-C/D), heading to the flight in 2012. The paper will provide an up-to-date insight on the IXV project, giving an up-to-date status of the design activities, the technological choices and the overall programmatic context.

EXPERT - A European Aerothermodynamics In-Flight Testbed

*Gavira, Jose
ESA-ESTEC*

EXPERT is developed by the European Space Agency in order to provide high quality data on the critical aerothermodynamic phenomenon encountered during hypersonic flights as well as to provide to industry system experience of re-entry vehicle manufacturing. The EXPERT is equipped with 15 experiments provided by several scientific institutions all around Europe. EXPERT will be launched from the Pacific Ocean into a sub-orbital trajectory by the Volna Russian launch system which is a submarine-based decommissioned ICBM. After a ballistic flight, it will land on the Kamchatka peninsula by means of a parachute. It will then be recovered for post-flight analysis. The launch is expected in 2010.

The collected flight results are expected to benefit all atmospheric re-entry activities ranging from future human and cargo orbital transportation systems to reusable launchers as well as scientific probes.

This paper describes the status of the EXPERT programme as well as the main challenges and the expected benefit.

Thermal Protection System (TPS) and Hot Structures Activity within the FLPP Core Technology Project

*Persson, J.; Jaredson, D..
ESA-ESTEC*

The general objective of the FLPP is to prepare the technical elements as well as the programmatic ones to make an informed decision on the best operational launch vehicle system - beyond the AS_KV European assets - responding to the future institutional needs, while maintaining competitiveness on the commercial market at that time.

The reusable NGL system concepts and IXV experimental vehicle development have spurred technology activities related to structures used in harsh environment. A variety of reusable TPS concepts have been developed and verified in this programme, addressing the requirements of future hypersonic vehicles. Based on the European past heritage, mainly three families of "passive" TPS are generally considered to achieve the required goals of future operational L/D efficient Orbit-to-Earth reusable hypersonic vehicles, namely: metallic panels, rigid CMC shingles and flexible ceramic blankets.

Reusable launch vehicles require as well highly loaded structural components, exposed to medium to high heat fluxes.

FLPP background and features of the activity dedicated to TPS and Hot Structures are presented in this paper along with current results of these studies.

Experimental and Numerical Entry Simulation at IRS

*Herdrich, G.; Fertig, M.; Loehle, S.; Bauder, U.;
Eichhorn, Ch.; Eiswein, N.; Haag, D.; Knapp, A.;
Lee, J.I.; Liebhart, H.; Majid, A.; Petkow, D.;
Preci, A.; Steinbeck, A.; Stindl, T.; Wernitz, R.
Institut für Raumfahrtsysteme (IRS)*

Activities in the field of TPS characterization and evaluation at IRS are highlighted. The accompanying investigations cover both experimental and numerical research work. Experimental activities are mainly related to the 4 plasma wind tunnels that are in operation at IRS.

These plasma wind tunnels are operated using rather powerful peripheral systems such as e.g. one of the most powerful vacuum systems or the respective electrical power supply system. During several decades the development of advanced measurement systems both intrusive (such as probes) and non-intrusive techniques (such as spectroscopic measurement systems) were emphasized. Besides important auxiliary facilities were procured and / or developed: One facility is a black body source used as reference radiator e.g. for the calibration of self-developed pyrometers. Another facility of importance is a black body based emissivity measurement facility (EMF) that allows for the determination of both spectral and total emissivities of typical high temperature materials. The combination of the aforementioned facilities and measurement techniques as such led to the development of unique methodologies e.g. in the field of catalysis and plasma-wall reaction schemes.

It is doubtless that such activities and also the understanding for the facilities and the atmospheric entries themselves cannot be covered without the use of adequate numerical tools. Here, a set of different codes dedicated for diverse purposes like both plasma source and flow simulation and simulation of thermo-chemistry, radiation simulation and the simulation of the atmospheric entry manoeuvre have been developed in the past decades.

The compilation of these resources and abilities led to the participation of the Department of Space Transportation of IRS in various re-entry projects such as MIRKA, X38, EXPERT and IXV and, in addition, various atmospheric entry related studies and development projects. Several living co-operations and co-operation contracts have been established with both institutional partners and industrial partners.

The paper reports on the abilities and related projects.

Plasma Power Handling in the ITER Fusion Device Challenges and Similarities with Thermal Protection Systems of Space Reentry Vehicles

*Federici, C. on behalf of the Fusion for Energy Team
Fusion for Energy*

Designing the interface between a thermonuclear plasma and the solid material environment is arguably one of the highest technical challenges of ITER and of future fusion power reactors. Although carbon-based materials are recognized to have superior thermal-mechanical properties and do not melt, they retain high levels of tritium by co-deposition with eroded carbon that could severely constrain plasma operations. Besides, in ITER even a carbon-fibre-composite divertor target would not survive long enough without reliable methods of mitigation/suppression of large ELMs. Metallic materials, as in the case of tungsten, would avoid the tritium retention issue, but melt layer losses due to large ELMs and disruptions, may lead to severe damage and unacceptably short lifetimes and, in addition,

maintaining plasma purity with high-Z materials remains a concern. A mix of several different plasma-facing materials as it is now proposed in ITER to optimise the requirements of areas with different power and particle flux characteristics (i.e., Be for the first wall, CFC for the divertor strike point tiles and W elsewhere in the divertor), but this is recognised to lead to cross-material contamination and the formation of material mixtures, whose behaviour in a tokamak is still uncertain.

The problems of power and particle exhaust of the plasma facing components of ITER, some of which are still at issue, are presented here. These include i) plasma thermal loads and material damage during normal operation and off-normal transients; and ii) engineering issues related to very high mechanical loads, with body forces resulting from induced currents during plasma disruptions, and thermal stresses resulting from a wide range of temperature profiles due to plasma and neutronic heating. These loads need to be reacted in a neutron environment, taking into account fatigue associated with the pulsed nature of the device, whilst allowing for reliable and expedient repair or replacement using remote handling tools.

An attempt will also be made to identify the main similarities and differences with the problem of heat protection of space re-entry vehicles, including, wherever possible, a comparison of conditions, requirements and material used.

Directions and priorities of future research to narrow remaining uncertainties in these areas are also briefly mentioned.

The Intermediate eXperimental Vehicle (IXV): the European Flight Opportunity for TPS&HS Technologies.

Denaro, Angelo¹; Langlois, S.²

¹NGL Prime S.p.A.; ²ESA - ESTEC

In the past years, Europe contributed to the technology improvement of different TPS&HS concepts through development activities carried out in the frame of many programs. The representativeness of the correspondent environment is one of the major on-ground facilities limitations that make flight experimentation an unavoidable complementary testing along the process of the hardware development.

In the frame of the ESA funded FLPP program, IXV is a flying demonstrator for integration of different re-entry technologies and for their experimentation into the real flight environment. Among them, TPS&HS assemblies have the opportunity to be integrated into the IXV demonstrator architecture in the most suitable areas for accomplishing in-flight experimentation fully representative of a return from Low Earth Orbit (LEO). The scope of the present paper is to provide an overview in terms of design solutions and in-flight

experimentation challenges foreseen for TPS&HS technologies to be embarked on the IXV.

In the IXV program, NGL Prime S.p.A. acts as industrial Prime under contract to the European Space Agency (ESA). The project has passed the System PDR at the end of 2008.

TPS & HS Subsystem Activities for IXV PDR Preparation

*Signorelli, Maria Teresa; Brach Prever, Elena;
Antonacci, Massimo
Thales Alenia Space*

The IXV mission represents an opportunity for the Thermal Protection System (TPS) & Hot Structures (HS) technologies developed in Europe in the past two decades to be flight verified.

The selection of the TPS & HS technologies to be embarked on the IXV has been mainly driven by the mission requirements and by the current Technology Readiness Level (TRL), with the primary objective to obtain the maximum possible TRL increase at an affordable cost. The need to utilize the TPS & HS elements essentials for the re-entry operations of such a demonstrator as well as the capability to comply with the vehicle architecture have also contributed to the definition of the TPS & HS architecture.

A notable engineering effort has been spent in the 2008 to reach a design maturity of the IXV technologies able to face with the program objectives and with the challenging schedule of the program which foresees the IXV flight in the 2012.

In the field of the TPS & HS and in the frame of the System PDR preparation the activities have been focused on the requirement establishment and management, on the design and interfaces definition, on the assessment of the actual TRLs and on the identification of the development and qualification program to be conducted on the various technologies before the flight.

These tasks have concerned all the disciplines involved into the TPS & HS product that is the IXV system, the TPS & HS architecture, the TPS & HS subsystem and the TPS & HS assemblies. This paper intends to describe the work conducted by Thales Alenia Space (TAS) - Italia in this context, in his role of subsystem responsible for the TPS & HS as part of the thermal-mechanical functional support to Next Generation Launcher (NGL). The activities related to the exchange of inputs with the IXV system and with the manufacturers of the different TPS & HS components will be stressed. Reference to the main outcomes of the tasks conducted by the latter will be also provided.

Thermo-Mechanical Design of the IXV Nose Assembly

*Knoche, Ralf¹; Rotärmel, W.²; Hald, H.²; Brach Prever, E.³; Denaro, A.⁴; Langlois, S.⁵
¹ASTRIUM Space Transportation; ²German Aerospace Center, Institute of Structures and Design; ³Thales Alenia Space - Italia; ⁴NGL Prime S.P.A.; ⁵ESA/ESTEC*

In the past decades CMC have proven their outstanding performance for TPS&HS. However, the corresponding technology suffers from the lack of validation through in-flight experience. This strong need including the strategic value for Europe led to the development of several experimental vehicles. The European Intermediate Experimental Vehicle (IXV) is the most recent re-entry vehicle which among other objectives aims at the remaining verification of advanced TPS&HS technologies in realistic flight conditions. Throughout these developments special attention has to be assigned to the Nose Assembly since it is generally exposed to the highest heat fluxes during re-entry. In consequence the Nose Assembly consists of the well established C/SiC materials (used e.g. for X-38) due to their superior characteristics such as high thermal resistance, low density, and high strength.

The paper describes the current status of the IXV Nose Assembly development. Thereby the Nose Assembly preliminary design is presented together with major thermal as well as thermo-mechanical analyses results. The paper concludes by defining the next essential steps within the development of the IXV Nose Assembly.

Thermal Non-Equilibrium in the Boundary Layer of a Flat Plate in RF Air Plasma

*Boubert, P.¹; Studer, D.²; Vervisch, P.³
¹CORIA, Université de Rouen; ²CORIA; ³CORIA, CNRS*

The composition of a subsonic air plasma created with an ICP torch was investigated thanks to optical diagnostics. Concerning N₂ and O₂, spontaneous Raman scattering was used to determine temperatures and density of their ground states. NO was studied by broadband laser-induced fluorescence and by emission spectroscopy. A clear discrepancy is shown between vibration and rotation temperatures in the plasma free jet and in the boundary layer of a flat plate. On the jet axis, densities were close to chemical equilibrium calculated at kinetic temperature. On the contrary, excited species were overpopulated. Concerning the flat plate, N₂ was found close to equilibrium. NO density increases near the plate which is explained directly thanks to Zel'dovich mechanisms.



ASA - A System Devoted to Hypersonic-Related Technologies

fossati, f¹; Marchetti, M²; D'Aversa, E³; Testani, C⁴; Marino, G⁵

¹Thales Alenia Space Italia; ²University of Rome "La Sapienza"; ³Italian Space Agency; ⁴Centro Studi Materiali; ⁵Centro Italiano Ricerche Aerospaziali

In the frame of the Advanced Structural Assembly program - founded by the Italian Space Agency - three plasma wind tunnel test were performed in order to evaluate the technologies developed in the frame of the hot-structures-based vehicles.

The lesson learned in the test campaign exploited in 2008-beginning 2009 is hereafter summarised

On Going Capabilities and Developments of Re-Entry Plasma Ground Tests in Eads-Astrium

*Van Ootegem, B.; Jullien, P.
ASTRIUM*

During re-entry, spacecrafts are subjected to extreme thermal loads. On Mars, they may go through dust storms. These loads are leading the design of re-entry vehicles or are affecting it for spacecraft facing solid propellant jet stream. Sizing the TPS requires a good knowledge of such solicitations and to reproduce them on earth. Through its work on European projects, ASTRIUM has developed the full range of competences to deal with such issues as the design and test of the Huygens probe heat-shield.

In particular, our plasma generators aim to reproduce a wide variety of re-entry conditions. Heat loads are generated by the huge speed of the probes. Such conditions cannot be fully reproduced. Ground tests focus on reproducing local aerothermal loads by using slower but hotter flows. Our inductive plasma torch enables to test little samples at low TRL. Amongst the arc-jets, one was designed to test architecture design of LEO return system and others fit more severe sample returns or Venus re-entry. The last developments aimed in testing samples in seeded flows. Special diagnostics characterizing the resulting flow enabled us to fit it to the requirements.

Thermal Protection Systems Portfolio of ASTRIUM GmbH - Recent Developments -

*Fischer, W.P.P.
ASTRIUM Space Transportation GmbH*

In recent years ASTRIUM has focussed on further development of its comprehensive TPS portfolio within following programmes: Pre-X & IXV, FLPP M&S, SHEFEX, EXPERT, new CTV's. Within the demonstrator programmes the blanket based/oxide ceramic TPS (FEI/SPFI) was further developed.

The metallic TPS called MERIT was further developed in the frame of the FLPP materials & structures programme. ASTRIUM participated to SHEFEX I. For SHEFEX II in principle the same experiments are foreseen with some modifications. In recent years several capsule configurations have been considered in ESA/national programmes. For these projects TPS work related to system aspects has been performed. This paper summarizes the recent developments at ASTRIUM GmbH concerning blanket based, metallic and oxide ceramic TPS.

CMC Thermal Protection System Pre-Development for Re-Entry Demonstrator Vehicles

PICHON, T.; BARRETEAU, R.; GIRARD, F.; LACOSTE, M.

Snecma Propulsion Solide

The paper will present the results achieved on both the Generic Shingle programme and the FLPP M&S Phase 1 programme. Extensive testing activities have been performed at material or sub-component level, full-size shingle component or multiple sub-components level, up to a complete C/SiC shingle and plasma cycle of a 3-shingle interface, as well as plasma testing of a complete array of three panels.

Today, a very high level of maturity has been achieved through the test campaigns performed. The few remaining open points will now be further studied at experimental vehicle development level, as well as in the frame of a second phase of the Material & Structures Technology programme. The current status of the development and qualification plan of the IXV windward CMC TPS will be presented, emphasizing in particular the TRL achieved to date, and showing the foreseen verification activities.

Investigations of Passive to Active Oxidation on C/SiC Hot Structures

*Infed, Farid; Handrick, K.; Steinacher, A.; Weiland, S.; Lange, H.
MT Aerospace*

Active oxidation occurring in hot structures based on C/SiC such as movable control surfaces, leading edges of TPS elements represents a critical event with negative consequences for future re-entry vehicles.

After a review of the principles of active to passive transition, the available results from plasma tests performed on MT's C/SiC material Keraman®/C/SiC are described. The information value of this data w.r.t. mission conditions as well as for the reliability of the measured data are discussed leading to a selection of possible governing material laws.

In a second section the results from thermal analysis of typical hot structure components for different re-entry

vehicles and capsules being subject of past research programmes as X-38, Pre-X, IXV, ESR&T and EXPERT are assessed w.r.t. the occurrence of active oxidation. The criticality for the mission is primarily determined by expected erosion rates and mass loss for the most endangered structural regions. Secondly, potential measures by means of design modifications to overcome the degradation by active oxidation are evaluated. Finally, the need for further tests to increase the data base is reflected.

TPS Joining Technologies

Marcos, J.¹; Jimenez, C.¹; Speliotis, T.²; Moutis, N.V.³; Azpiroz, X.¹; Mergia, K.³

¹FUNDACION INASMET; ²Institute of Material Science - NCSR "Demokritos"; ³Institute of Nuclear Technology and Radiation Protection - NCSR "Demokritos"

Advanced carbon or carbon composite materials are intended used in future space TPS and hot structures or other applications in fusion and fission. Joining of these ceramic materials to metals is required in a number of advanced applications and in many cases these joints have to operate at extreme environments as high temperatures, oxidizing and corrosive atmospheres and under mechanical loads. Successive thermal cycles may generate aging and failure of the joint due to large internal stresses arising from the different thermal expansion coefficients (CTE) of such dissimilar materials.

The paper present various alternatives of metallization and smodification of the composite surface in order to compensate the large CTE mismatch. Further, such a surface modification should assure good adhesion to the ceramic, high temperature phase stability and mechanical strength. Experimental work onto graphite sheet has been successfully brazed to a Nimonic 105 superalloy using a commercial TiCuSil paste.. This work has been carried out within the framework of the Integrated European Project "ExtreMat" (contract NMP-CT-2004-500253) with financial support by the European Community.

Development and Verification of an Instrumented Aerothermal Thermal Protection System Heat Shield Plug for Flight on the Mars Science Laboratory

Martinez, E.¹; Martinez, E.R.²; Santos, J.³

¹NASA; ²NASA Ames Research Center; ³Sierra-Lobo Inc.

This paper shall discuss the development, testing, and verification of performance for thermal protection system aerothermal instrumentation that has been installed into NASA's Mars Science Laboratory heat shield. We shall describe the approach of integrating thermocouples and an isotherm following 'recession'

sensor into seven plugs placed uniformly across the surface of the aeroshell.

Advanced Heat Flux Measurement during Re-entry Flight using The Non-Integer System Identification (NISI) Procedure

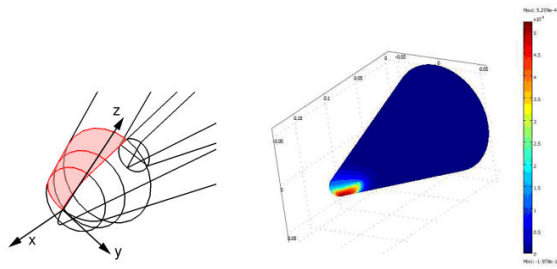
Lohle, S.¹; Battaglia, J.L.²

¹University of Stuttgart; ²University of Bordeaux

One of the major and simultaneously most crucial problems within the experimental characterization of re-entry flights is a reliable high accuracy heat flux measurement system within the nose tip. Up to now most of heat flux systems on ballistic re-entry flights are based on so-called slug calorimeters. The major drawbacks of this system are on the one hand its rather low mission limit and on the other hand the system immanent problem of the catalycity of the used slug material (usually copper under the assumption of rather high catalycity). Hence, a measurement system with high accuracy, fast response and less limitation in heat flux amount is needed in order to significantly improve the heat flux measurements. Moreover, since modern heat shield concepts are often based on new material developments, a method is wanted that measures the heat flux directly using these new materials.

From a theoretical point of view, the heat flux is deduced from thermocouple measurements which in principle is not new. However, modern data analysis tools together with an advanced calibration step allow taking into account the disturbing effects of such a sensor and its inverse methods, i.e. radial heat fluxes and thermocouple inertia or position. The theoretical approach is based on the NISI method (Non-integer system identification), which has been proved at EADS-ASTRIUM and IRS for high heat flux measurements in plasma windtunnels. Within this paper, a simple heat flux measurement system is proposed which measures heat flux on the real heat shield material within the tip. In a first step it is shown that using the NISI method, heat flux can be deduced in complex geometries. Finally, the method is applied to 3D configurations, because especially in crucial nose regions, where other measurement techniques bring high mission risks, the simple thermocouple measurement is the leading advantage.

Assuming the usage of several thermocouples the extension of the method to several thermocouples will be shown. This can then be used also to locate the region of highest heat flux of a re-entry capsule leading edge and a possible tumbling of the vehicle can be taken into account.



Simulation of heat flux to one quarter of the tip of a nose geometry.

DEDALO: Thermo-Mechanical Monitoring by Fiber Optic Devices on UHTC Structures

Latini, V.¹; Striano, V.²; Monteverde, F.³; Rendina, I.⁴; Parolini, C.⁵

¹S.A.B. Aerospace; ²Carlo Gavazzi Space; ³CNR-ISTEC; ⁴CNR-IMM; ⁵Bettini Technical Division

In aerospace applications the development of a reliable method of structural health monitoring (SHM) is one of the most important keys in maintaining the integrity and safety of structures.

The research program DEDALO aims at developing a real size UHTC-based prototype with a complex shape equipped with a SHM system for damage detection. A multidisciplinary approach has been adopted involving mechanical design, investigations on material and manufacturing processes and development of optical devices to detect strain and temperature on UHTC. Former activities merged into the manufacturing of a prototype hot structure supplied with optical sensing nodes to perform a functional test at high temperature. This communication describes the preliminary findings of the project.

Airborne Re-Entry Observation Experiment SLIT: UV Spectroscopy During Stardust and ATV Re-entry

Loehle, Stefan; Eichhorn, C.; Herdrich, G.; Knapp, A.; Wernitz, R.

Institut für Raumfahrtssysteme (IRS)

Researchers at IRS participated in two recent airborne observation campaigns: The re-entry of the Stardust capsule in 2006 and that of the first ATV in 2008. Both missions had the same scientific goals: First, the realization of emission spectroscopy of the plasma radiation emitted during re-entry in the higher atmosphere to obtain information about the plasma state, and, second, the identification of the main characteristics as e.g. the surface temperature in case of Stardust and the main breakup situations in case of ATV.

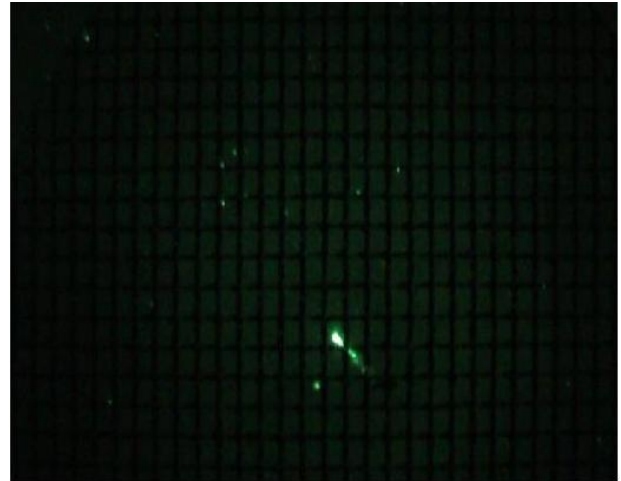


Fig. 1 shows an image of the re-entry of ATV as seen by the tracking camera. In this paper, the experimental setup of the tracking camera and the spectrometer is illustrated. The calibration of the experiment is described and first flight data analysis is presented. The second figure shows the spectra as measured during the ATV-re-entry.

The Sharp Edge Flight Experiment SHEFEX II, a Status Report

Weihs, H.¹; Longo, J.M.²; Gülhan, A.²; Turner, J.²

¹German Aerospace Center; ²German Aerospace Center DLR

After the successful flight of SHEFEX I the next mission is under development. Within this paper the basic goals architecture of the SHEFEX II mission will be presented. Launched by a two staged sounding rocket system SHEFEX II will be a consequent next step in technology test and demonstration. Considering all experience and collected flight data obtained during the SHEFEX I Mission, the test vehicle was re-designed and extended by an active control system, control during the re-entry phase. Thus, ceramic based aerodynamic control elements like rudders or flaps, mechanical actuators and an automatic electronic control unit will be implemented. Special focus will be taken on improved GNC Elements. In addition, some other experiments including an actively cooled thermal protection element, advanced sensor equipment, high temperature antenna inserts etc. are part of the SHEFEX II experimental payload. During the experiment phase a maximum entry velocity of Ma 10 to 12 is expected for 60 seconds. Thus, the heat loads will cause a temperature distribution between 2000°C at the sharp leading tip and up to 900 °C at the rear panels.

Design and Thermo-Mechanical Analysis of the Aerodynamic Control Surfaces on SHEFEX-II

Elsäßer, H.¹; Weihs, H.²

¹Institute of Structures and Design; ²Institute of Structures and Design, Deutsches Zentrum für Luft- und Raumfahrt

SHEFEX II is a re-entry technology demonstrator for future cost-effective re-entry vehicles with faceted shape and sharp leading edges. One of the experiments on board is the Canard-System for attitude control during re-entry.

This paper describes the design and thermo-mechanical analysis of the SHEHEX II Canard-wings. It focuses on the hybrid design due to the high temperatures at the sharp leading edges and the high mechanical load at the Canard-root. The major challenge is the interface between the leading edges made of DLR's C/CSiC and the canard root made of titanium with the problem of the different coefficients of thermal expansion of C/C-SiC and Titanium.

SHEFEX II Flight Instrumentation

Thiele, T.; Siebe, F.; Guelhan, A.

German Aerospace Center

For a low cost access to space with a high level of reliability, the design cycle duration has to be reduced and the service and refurbishment of the space vehicle have to be simplified. A complex geometry of the TPS components of operational space vehicles like the Space Shuttle leads to expensive manufacturing and maintenance processes. TPS structures consisting of flat ceramic panels could be a realistic solution to reduce the costs and improve the aerodynamic performance of space vehicles.

Although ground testing still provides the main validation data, a complete simulation of the flight conditions is mostly not possible. Therefore flight experiments are the most effective tool to obtain validation data for the design under real conditions. To test these new sharp edged TPS structures (flat panels) the DLR successfully performed the SHEFEX I flight experiment and is now preparing a second flight experiment SHEFEX II in 2010.

The SHEFEX II flight configuration includes more than 100 different sensors and a new type of Flush Air Data System for the sharp edged configuration, which will be tested during flight and pre-flight qualification tests.

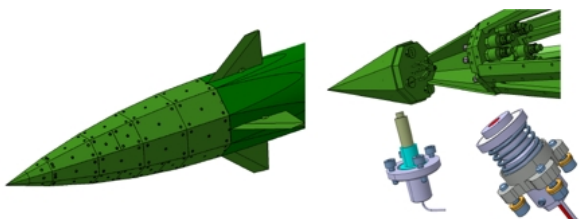


Figure 1: SHEFEX II fore body (left), Nose with FADS transducers, pressure port, HFM interface (right)

Thermal Conductivity Measurements under Non-Standard Conditions

Vidi, Stephan; Ebert, H.-P.

Bavarian Center For Applied Energy Research

For the precise determination of the thermal conductivity various stationary and instationary experimental methods are well established. Best practise is documented in written standards and literature. It is obvious that the lowest uncertainties can be reached if the measurement method, the experimental conditions and the specimen properties match the theoretical model for the experiment.

However these ideal conditions are not often given, especially in the case of thermal insulation used for space applications, where extreme operating conditions (high temperatures, non-standard gas pressures) and specialised thermal insulation concepts, like MLI, abrasive layers, have to be considered.

We will present measurements for the determination of the thermal conductivity conducted under non ideal conditions using three of the most common measuring methods (i.e. guarded hot plate, laser-flash and hot-wire). We will point out typical problems that can arise and that can have a major impact on the final results. Finally some of the possible solutions to ensure high measurement quality will be discussed.

High Temperature Thermal Conductivity Measurement Apparatus

Selzer, M.¹; Reimer, T.¹; Keller, K.²; Ritter, H.³

¹DLR; ²Keltec; ³ESA

For thermal conductivity measurements of insulations for re-entry applications, the HitCon test apparatus was developed. It was designed to measure thermal conductivities ranging from 0.015 W/mK to 0.8 W/mK in the temperature range from 400°C to 1600°C and within a pressure range 1 mbar to ambient pressure. For precise measurements, HitCon minimises parasitic heat fluxes by design and uses in addition a correction algorithm to account for residual parasitic heat exchanges. An operation demonstration campaign on three typical insulations - Saffil, IMI and Pyrogel - revealed results, which compare well to available data.

In the paper, the HitCon test apparatus together with the correction algorithm is described and results from the operation demonstration campaign are presented.

The Use of Flash Methods to Determine Thermal Conductivity

Hohenauer, W.

Austrian Institute of Technology AIT

In 1960 Parker et al first time described a flash method to determine thermal diffusivity, heat capacity and

thermal conductivity. In the meantime flash methods became acknowledged as excellent methods to measure thermal diffusivity. Specific heat preferably is measured with calorimeters.

During the last years flash methods increasingly became used for applications subjected to methods for thermal conductivity measurement. This can be drawn back to it's applicability in a wide temperature range (about -150°C up to 2000°C and more), to the low uncertainties of measurement results compared to those data obtained from facilities to measure conductivity, and the availability of mathematical methods to extract diffusivity from the detected temperature behaviour of a specimen. Hence anisotropic materials as well as partly inhomogeneous materials became measurable by flash methods. Additionally time needs and costs for flash measurements are significantly lower than costs for most methods to measure thermal conductivity.

This contribution overviews possibilities and limits of flash methods. Its application to provide a comprehensive thermal analysis will be described.

TPS Design Methodology for the EXPERT capsule

*Thoemel, J.; Walpot, L.; Thirkettle, A.;
Ratti, F.; Gavira, J.
ESA*

The TPS design methodology of the EXPERT capsule is presented.

First, heat fluxes and pressure distributions are obtained computationally. They are used as input for a thermal response computation of the heat shield.

The design takes into account various physical aspects as catalysis, radiation, thermal expansion, deformation, the onset of transition and the transition from passive to active oxidation.

It is found that high uncertainties due to numerous aerothermodynamic phenomena, which are poorly understood, have to be taken into account.



TPS Design, Development and Verification Approach for EXPERT Program

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Thales Alenia Space - Italia*

The EXPERT (European eXPERimental Re-entry Test bed) capsule is a re-entry vehicle designed to perform a ballistic hypersonic flight in the Earth atmosphere. The objectives are to demonstrate the feasibility of using hot structures for re-entry vehicles, gain information on in-flight behaviour of metallic and ceramic TPS materials, enable in-flight measurements of critical AD/ATD phenomena such as laminar-to-turbulent transition, material catalysis, shock wave/boundary layer interactions, etc. CMC Nose and metallic PM1000 Cone TPS form the aerodynamic shape of the capsule. TPS Cone development will rely on a Proto-Flight Model (PFM) philosophy and a full-scale hybrid PM1000/Stainless Steel Breadboard. The Breadboard is built to verify critical manufacturing aspects and to validate the Assembly and Integration procedures in an early stage of the program. In parallel with the material characterization tests, PM1000 manufacturing trials are foreseen to verify the assumptions made in the TPS design and tune the process parameters, to allow for the manufacturing of a First Article made of PM1000 for a critical corner piece (curved panel).

Thermal-Structural Performances of the EXPERT Thermal Protection System

*Fatemi, J.
Dutch Space*

The EXPERT TPS is designed to meet insulating and structural requirements resulting from the different mission phases i.e. launch and atmospheric re-entry. Thermal and structural FE models are developed to predict the thermal and thermo-mechanical performances of the TPS subjected to mechanical and aerothermal loads during launch and re-entry phases. A modal analysis is first carried out to determine the modal characteristics of the TPS and to verify the compliance with the minimum frequency requirement. Static FE analysis is performed to verify the strength of the TPS during the launch phase.

Transient FE thermal analysis is carried out to predict the temperature history in the different parts of the TPS during the atmospheric re-entry phase. After calculation the temperature history, the combined temperature field and aerodynamic pressure are applied to the structural FE model to predict the thermo-mechanical performances of the TPS in terms of deformations, strains and stresses during the re-entry phase. The FE analyses results show that the EXPERT TPS is able to withstand against the mechanical loads during the launch phase and aerothermal loads during the re-entry phase.

Thermo-Mechanical Design of The Expert Nose and Testing of The Load Introductions

Reimer, T; Stubicar, K
DLR

EXPERT is a mission to gather precise in-flight data of the re-entry aerothermodynamic environment. That led to the selection of a ceramic matrix composite heat shield as the Thermal Protection System (TPS) for the nose of the vehicle. The Instrumented Nose Assembly (NAP) is a sub-system of the EXPERT vehicle, consisting of the CMC nose cap and embedded payloads to measure temperature, heat flux and spectroscopic data. Since EXPERT is a vehicle with a high ballistic coefficient the aerodynamic pressure in the stagnation area reaches a value of 1.5 bar. During re-entry the peak heat flux will reach up to 1.5 MW/mm and the predicted temperatures will reach up to 2050°C in the capsule front. Due to the very large temperature gradients between hot surface and internal cold structures the problem of mismatching thermal expansion has to be solved. At the same time the nose has to withstand the high pressure loads. The paper describes the design of the nose and the load introductions attaching the nose to the vehicle. The thermo-mechanical analyses as well as mechanical tests of the load introduction are presented. Full scale tests under vibration and shock loads will be briefly discussed.

Development of a European Ablative Material for Heatshields of Sample Return Missions

Ritter, H.¹; Portela, P.²; Keller, K.³;
Bouilly, J.-M.⁴; Burnage, S.⁵
¹ESTEC; ²HPS-Ltda; ³HPS GmbH; ⁴EADS-Astrium;
⁵Lockheed Martin UK

The Earth return from extraterrestrial bodies (e.g. Mars, asteroids or comets) involves a hyperbolic trajectory resulting in atmospheric entry velocities of typically around or above 12 km/s and resulting peak heat fluxes exceeding 10 MW/m².

ESA is currently studying the architecture of a potential joint Mars Sample Return (MSR) mission in cooperation with NASA/JPL. In parallel, the feasibility of a NEO (Near-Earth Object) sample return mission, named Marco Polo, is under investigation. Both missions would include an Earth re-entry capsule experiencing entry velocities as mentioned above.

The choice of a suitable TPS material for such missions is predominantly driven by the high peak heat flux levels and the stringent mass requirement. ESA has recently initiated together with HPS a dedicated activity aiming at the development of a European lightweight ablator material for extreme heat flux applications. Initial development is starting from two independent routes, followed by Astrium and INSYS. A preliminary characterisation is planned to be performed in 2010. The paper will review the requirements coming from the mission studies and outline the initial material development approach.

Enhanced Ablative TPS Study for High-Energy Entry Missions

Fossati, F.¹; Simone, A.²; Saluzzi, A.²; Valente, T.³;
Pulci, G.³; Tirillò, I.³; Gardi, R.⁴
¹Thales Alenia Space Italia; ²Thales Alenia Space;
³University of Rome "La Sapienza"; ⁴Centro Italiano
Ricerche Aerospaziali

In the frame of the CSTS-Breadboarding Study - under ESA funding - a light ablative thermal protection dedicated to high-energy re-entry missions was partly developed and preliminarily tested in a small Plasma Wind Tunnel in order to assess the status and the perspectives of the concepts considered and their possible future enhancements. The report summarises the present activities status and presents the results so far carried out.

Mechanical and Ablative Properties of Silica-Phenolic Composites for Thermal Protection Systems

Gregori, M.L.¹; Barros, E.²; Petraconi, G.²; Costa, S.¹
¹Institute of Aeronautics and Space; ²Technological
Institute of Aeronautics

In this work silica-phenolic resin based ablative composites have been characterized with the intention to evaluate composite materials for thermal protection systems to be used in the Brazilian Reentry Satellite (SARA). This study used as parameter the characteristics of the silica fabric (woven or chopped). The option for studying different sorts of silica fabric lies in the possibility to solve problems of delamination and molding in thermal protection systems of large dimensions and complex formats. We focussed our interest in the evaluation of the effects of the characteristics of woven silica fibers (weaved with aligned fibers in a single plan) and chopped silica fibers (random domains of orientation of fibers) over their ablative, thermal, mechanical and microstructural properties.

Estimating Properties of Materials Interacted with High-Enthalpy Gas Flow by Inverse Problems Technique

Nenarokomov, A.V.¹; Artiukhin, E.A.²; Titov, D.M.³
¹Moscow Aviation Institute; ²University of Franche-Comte; ³Moscow Aviation Institute

Results are presented in the paper on mathematical modeling with respect to a simultaneous determining of the emissivity and thermal effect of sublimation as functions of temperature for material interacted with gas flow. Inverse Problems solving is based on temperature measurements on the internal points of material (coordinates of thermocouples installation in specimen) and some other parameters. Direct measurement of the

great number of parameters is often impossible. A method analyzed in this paper for determining unknown heat transfer characteristics is based on the iterative regularization of inverse problems.

1. E. A. Artyukhin, A. V. Nenarokomov, Identification of characteristics of the thermal interaction of materials with gas flows, High Temperature, 28, 247 (1990).

Status of the IRS EXPERT Instrumentations PYREX, PHLUX and RESPECT

*Roeser, H.; Löhle, S.; Lein, S.; Preci, A.; Steinbeck, A.;
Wernitz, R.; Auweter-Kurtz, M.; Herdrich, H.
University of Stuttgart*

Measurement systems developed at IRS have been developed and/or flown aboard vehicles such as EXPRESS, MIRKA, IRDT and X38. For the European capsule program EXPERT miniaturized flight experiments being developed at IRS are presented. PYREX, a pyrometric entry experiment, measures rear side temperatures and heat fluxes on ceramic TPS. It has already been flown (EXPRESS, MIRKA). PYREX-KAT38 is a fully qualified six-channel measurement system and was intended to be operated aboard the X-38. A similar design is being further developed for temperature and heat flux measurements in the nose structure of the EXPERT capsule. PHLUX (Sensor system for catalytic experiments) is a pyrometric catalysis based sensor system being developed for the EXPERT capsule. The flight experiment aims to estimate the dissociation degree during the entry using measured heat fluxes on different catalytic surfaces. RESPECT is a spectrometer to be used to gain spectral data in the flow field around EXPERT during its entry. The main goal is to obtain more detailed information about the plasma state in the post shock regime by measuring the spectrally resolved radiation onto the surface. The data will be used for the comparison with results of numerical simulations to validate of aerothermodynamic models. At present the qualification phase is at its end and the flight models are being manufactured.

In 2006 IRS participated in the airborne observation mission for STARDUST using a spectroscopic set-up developed specifically for this purpose on basis of a laboratory spectrometer. Presently, three different in-flight measurement systems are being developed at IRS for the aerothermodynamic demonstrator capsule EXPERT. A further combined system called COMPARE is in the design phase for SHEFEX2. In addition, the data of the observation mission for the entry of ATV the end of September 2008 is being evaluated.

EXPERT Open Flap Assembly and its Instrumentation

*Gülhan, A.¹; Siebe, F.¹; Thiele, T.¹; Handrick, K.²
¹Institute of Aerodynamics and Flow Technology; ²MT
Aerospace*

The main objective of the EXPERT Payload 6 "Measurement of Control Surfaces Aerodynamic Efficiency and Heating" is the measurement of the pressure, surface temperature and heat flux rate on the control surfaces assembly. The sensor integration into the hot structure of the flap (MT-Aerospace) and the cavity (Dutch Space), and the associated data acquisition system integrated into the cold structure require special care concerning the interface problems. The specification and distribution of the instrumentation have been performed in such a way, that both aerodynamic flap efficiency and aerothermal heating in the complete control surface assembly can be measured accurately. The Payload 6 components are exposed to severe aerothermal loads of a high enthalpy flow field and therefore required the consideration of following physical processes as the design drivers:

- High aerothermal loads due to the re-attachment of the separated high enthalpy flow on the flap surface and on the cavity side walls.
- Increase of the aerothermal heating due to the boundary layer transition on the flap.
- Cavity surface heating due to the radiative heating from the hot ceramic flap rear surface.
- Possible deformation of the ceramic flap under aerodynamic loads.
- Dynamic loads during launch and stage separation.
- High thermal expansion coefficient of the cavity material (compared to the CMC and C/C-SiC used for the instrumentation).
- Limitation to the mass with respect to the overall mass budget of the vehicle.
- Limitation to the data acquisition rate due to overall system constrains.

For the pressure ports at the flaps C/C-SiC inserts in the flaps are used. Since the pressure transducers themselves have to be mounted at the cold structure below the cavity, high temperature tubes passing through the cavity near the hinge line have to be used. Type S thermocouple is used at the flaps and type K is used at the cavities. The heat flux microsensors are used to resolve the span wise distribution of the heat flux onto the cavity. In addition a pyrometer with miniaturized optics is integrated to measure the flap rear surface temperature.

After the calibration check of each sensor type several thermal, mechanical, vibration and vacuum tests are carried out on both mechanical and electronic components of the payload. For the flap instrumentation first a detailed thermal analysis was performed to get the complete information of the sensor behaviour in a severe aerothermal environment. In addition aero-thermal design verification tests have been carried out on the pressure port mounted to a CMC flap model in the arc heated facility L3K. These tests demonstrated the feasibility of the pressure port design at EXPERT flight

conditions. Complementary to the experiments a detailed thermal analysis was performed to get the complete information of the sensor behaviour in a severe aerothermal environment. After the successful CDR the manufacturing of the payload elements started and the complete hardware and software will be available within this year.

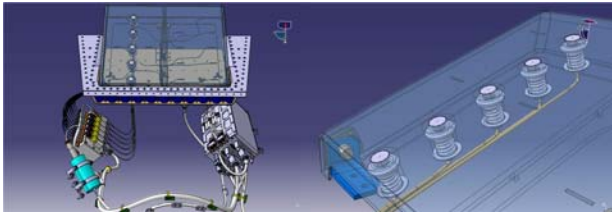


Figure 1: Instrumentation layout of the EXPERT flap assembly.

Thermal Measurement Techniques for Movable Control Surfaces in Re-entry Vehicles

Pereira, C.
RUAG Aerospace Wallisellen

This paper describes the use of two techniques to map temperatures of a steerable re-entry vehicle control surface: IR thermography and thermocouples. Emissivity is a function of temperature, viewing angle and degree of oxidation of the observed target (figure 1). In trying to determine temperatures optically a continuous measure of emissivity independent from temperature is required.

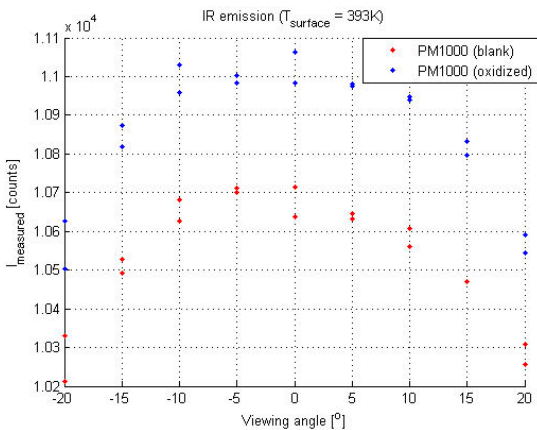


Figure 1- Variation of emissivity with angle and oxidation

The proposed solution is the use of a multicolour filter with narrow band passes which simulate 4 wavelength channels with cut-off wavelengths at 1.5, 1.55, 1.6 and 1.65 μm (near infrared) and a 100 nm bandwidth. The system is implemented in the image plane (figure 2).

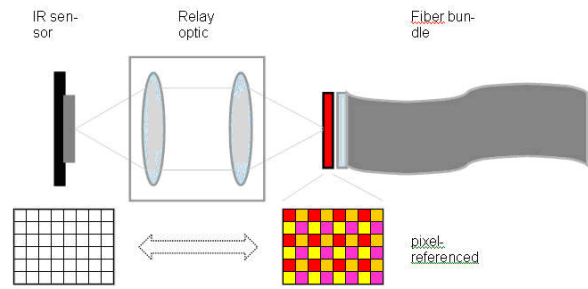


Figure 2- Schematic of NIR Filtering

A simulation of this technique resulted in an error of emissivity of 13-15%, however the accuracy of the temperature measurement is still within 3%

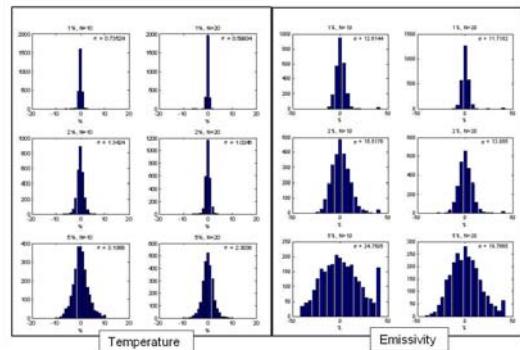


Figure 3- Predicted Accuracy

The main challenge for thermocouples is the displacement together with the surface (figure 4). Type S and C thermocouples were tested for performance with respect to solid state reactions and fatigue. (figure 5)

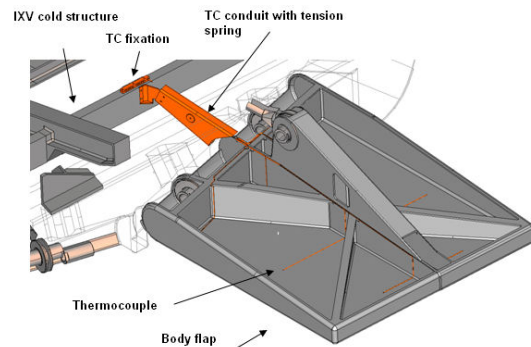


Figure 4 Schematic of Thermocouple Placement in a Moving surface

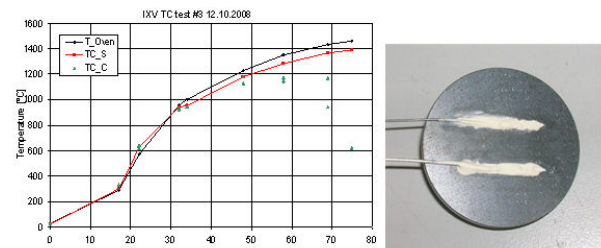


Figure 5 Thermocouple Behaviour

Qualification of a Ceramic Fin for Flight on European Experimental re-entering Capsule EXPERT

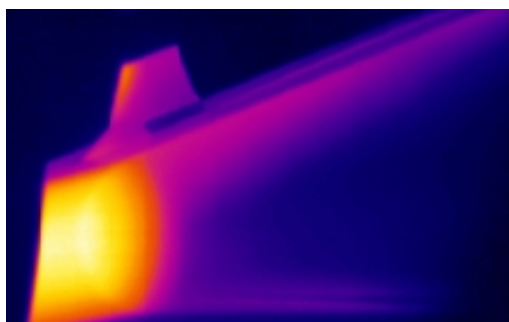
Del Vecchio, A.; Marino, G.M.; Gardi, R.G.
C.I.R.A. Italian Center for Aerospace Research

In the frame of the activities aimed to develop advanced ultra high temperature ceramic materials (UHTC) for space applications, CIRA is conducting a challenging project, finalized to test two ceramic fins in a real hypersonic re-entry environment, as payload on the EXPERT capsule.

The Winglets are placed in the aft region of the capsule, in two symmetric locations.

P After a complex design phase, supported by massive FEM and CFD analyses, a qualification model of the payload has been realized and has been subjected to mechanical and thermal tests. The mechanical qualification campaign, conducted at CIRA, consisted in sinusoidal and random vibrations, up to 30grms, and in shock test, up to 1000g acceleration.

Big efforts were required to design an aerodynamic holder capable to reproduce the spatial heat flux distribution on the winglet, reproducing, in the different fluido-dynamic condition of the facility, the effects of the boundary layer generated by the whole capsule length during the flight atmosphere. In order to reproduce the flight heat fluxes levels, the SCIROCCO facility was required to operate at very high conditions (53MW power and 13MJ total enthalpy).



Ablation Response of Fibrous Materials with Different Matrices: Modeling, Comparison, and Application

Lachaud, J.¹; Mansour, N.N.²

¹NASA Postdoctoral Program / NASA Ames;

²NASA Ames

A multiscale approach is used to model and analyze the ablation response of carbon-fiber preforms impregnated in phenolic matrix. This is basically the structure of the Phenolic Impregnated Carbon Ablator (PICA) material used for Stardust. Direct numerical simulations at microscopic scale show that carbonized phenolic matrices are ablated in volume leaving the carbon fibers without protection. When the matrix is removed, the fibers themselves are ablated through a progressive reduction of their diameter. The overall material recession occurs when the fibers are consumed.

Materials with the same carbon-fiber preforms and chemical compositions, but with different matrix distributions are shown to display different ablation behaviors; a fact that is not captured by current models that are based on chemical composition only. To enable engineering scale applications, the microscopic model is averaged in space, and a set of partial differential equations describing the macroscopic behaviors of the materials is derived. The macroscopic model is applied to Stardust re-entry conditions. The model reproduces the drop in density measured at the top of the char layer of the Stardust TPS.



Design and Numerical Modelling of Charring Ablators for Re-Entry Applications.

van Eekelen, T.¹; Bouilly, J.-M.²; Hudrisier, S.²;
Dupillier, J.-M.²

¹Samtech s.a.; ²Astrium-ST

For scientific missions into a planet's atmosphere, the development of the thermal protection system (TPS) of the re-entry vehicle is a technology critical to the success of any such mission. A re-entry capsule will enter the planet's atmosphere from an interplanetary trajectory and the accompanying heat flux can have values ranging from 0.5 to 15 MW/m². Although this heat flux range is large, the choice for a weight efficient design is generally directed towards an ablator design, due to the fact that the TPS only needs to be used once. This paper describes the tool developed by Samtech and used by Astrium to design charring ablaters for re-entry applications.

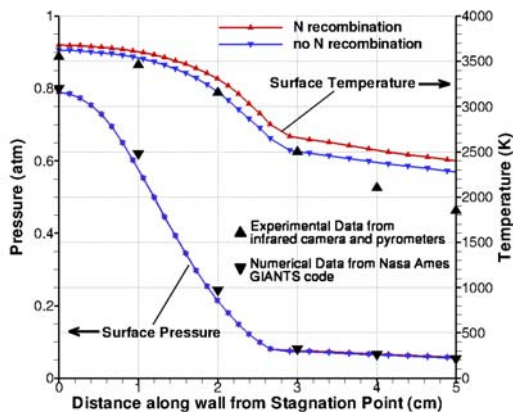
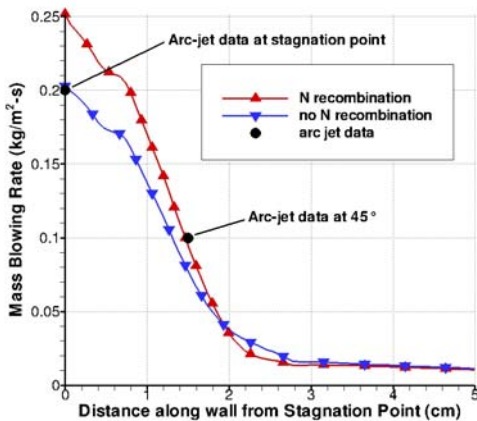
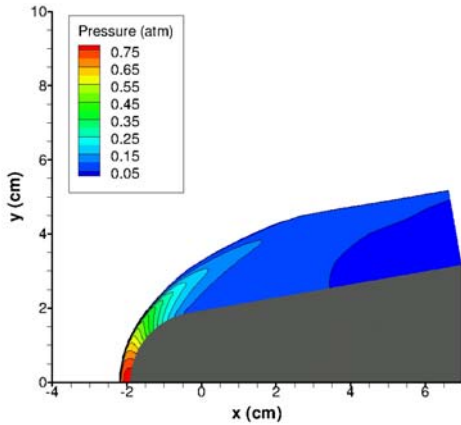
Navier-Stokes Simulations with Graphite Surface Ablation for Atmospheric Entry

Bianchi, D.¹; Martelli, E.²; Nasuti, F.¹; Onofri, M.¹

¹Sapienza University of Rome; ²II University of Naples

A widespread approach used to protect space vehicles is the use of ablative materials. For high velocity atmospheric reentry problems the heating rates are such that ablation of the heat shield material occurs to a substantial extent. Non-charring TPS materials, such as carbon-carbon, are used in high heating environments. CFD codes typically treat surface boundary conditions in a simplified manner such as constant prescribed temperature or heat flux with zero mass transfer. However TPS materials strongly interact with the flow so that simple CFD surface boundary conditions cannot

realistically be used for TPS design. In this work, a general surface boundary condition with mass and energy balances and a thermochemical ablation model integrated with a multi-species reacting Navier-Stokes solver is adopted. The capabilities of the present numerical approach are shown for axisymmetric flowfields over carbon-carbon blunt bodies assuming diffusion limited ablation. Figure 1 shows the pressure field with the bow shock and Figure 2 and 3 show a comparison between the computed surface blowing rate and temperature distributions and the experimental data taken from a recent arc jet test.



Numerical Rebuilding of Ablative Test Cases Using KCMA

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ISA

In the frame of the European Ablation Working Group, two test cases based on experimental results obtained for ablative material have been defined in the perspective of a numerical rebuilding. The first one consists of a data set obtained for artificial graphite in a high-enthalpy wind-tunnel while the other is dedicated to carbon-phenolic.

Here, both test cases are rebuilt using KCMA. This tool is based on a one dimensional approach and uses a surface energy balance at the surface of the material. It can account for several phenomena such as pyrolysis, material porosity, sublimation and oxidation. The tool has been already validated using the available results obtained during the Pioneer-Venus mission. First results show the capabilities of the tool to recover the evolution trends of the material recession for high-enthalpy tests performed with graphite. However, some improvements could be performed by testing the different correlations for sublimation and oxidation available in the literature. In a second step, the second test case will be rebuilt. Using the numerical results some issues such as the interest of accounting for material porosity will be discussed.

ASTRIUM's TPS Experiments on SHEFEX II - Design & Analyses - Fischer, W.P.P.; Knoche, R. ASTRIUM GmbH

ASTRIUM has developed within the last 2 decades a comprehensive portfolio of TPS ranging from metallic over blanket based to ceramic (oxide, C/SiC) ones. Generally, these TPS has gained high maturity and verification has been done based on comprehensive ground testing. However, experience with flight testing for most of the candidates is limited. For this reason DLR's SHEFEX II offers an excellent opportunity to increase experience for the entire chain of TPS work ranging from analysis to evaluation. Like for SHEFEX I were most of the now for # II proposed experiments have been already flown, 4 of ASTRIUM's TPS technologies are foreseen. This paper describes the design, thermal and therm-mech. analyses performed in the first phase of preparation and expectations as well as further proceeding.

Design and Layout of the Combined Sensor System COMPARE for SHEFEX II

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The German Aerospace Center DLR is planning the launch of the suborbital mission SHEFEX II in the year 2010. The maximum velocity of 3.5 km/s will be reached at 35 km altitude. The Institute of Space Systems (IRS) is developing the combined sensor system COMPARE for SHEFEX II. The goal of this system is to simultaneously measure the temperature of the TPS, the radiative heat flux and absolute pressure. The gained data will allow the reconstruction of important trajectory parameters. The temperature of the rear side of the TPS panel will be measured by using a pyrometer. The measurement of the radiative heat flux will be performed with a thermopile, and since the radiometer needs an optical access to the surrounding plasma the pressure will be measured in the radiometer cavity just in front of the protecting window. The designed window assembly has been analysed thermo-mechanically by applying the SHEFEX II loads. Furthermore, the interface between the aluminum panel of the vehicle and the sensor unit has been numerically analysed. An engineering model of the window assembly has been designed on a basis of a plasma wind tunnel (pwt) double probe. Measurements in a pwt are planned.

Heat Balance of the Transpiration-Cooled Heat Shield Experiment AKTiV on SHEFEX II

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DLR (German Aerospace Center)*

SHEFEX II is a re-entry technology demonstrator for future cost-effective re-entry vehicles with faceted shape and a sharp leading edge. One of the experiments on board is the actively transpiration-cooled AKTiV. Active cooling systems are of interest for use in severe thermal environments.

The present paper gives an analytical method to determine the expected heat flux to a tilted heat shield of a vehicle. The cooling mechanisms are described in detail and in order to pre-estimate the cooling efficiency of the transpiration, a heat balance is derived. Based on experimental results, this theoretical approach will be applied to DLR's C/C ceramic material, through which a coolant is injected into the boundary layer, and to the particular case of the SHEFEX II mission's experiment AKTiV.

Upgrade of Three Laboratory Test Setups to Measure Material Properties and Antenna Models at High Temperatures Occurring during Re-entry Vehicle Flights

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Commitment to maintain permanent human presence on earth orbit and consideration given to manned missions beyond earth orbits, has established a need to develop modern re-entry cargo and manned vehicles at ESA. Development of a new category of spacecraft shall preferably make use of proprietary technology under ESA and it calls for intensive studies aiming at closing some existing loops in technical, material and test issues. Among highly ranked problems are antennas, tests of such antennas and materials of which they are built.

To carry on development of such antennas we plan to build three measuring setups for measurements: (i) electrical properties of dielectric materials, (ii) impedance of microwave circuits and antennas, (iii) radiation pattern with the near-field technique. They all three are based on already existing systems, that we have developed in-house over years and which are in operation for several years. The major challenge is to make feasible measurements of antenna/material exposed to high temperatures featuring values at least 1000°C. We plan to adopt existing measuring methodology with substantially re-written test procedures. Limits of measurement frequency range primarily depends on microwave equipment and accessories used. However, measurement accuracy is related to temperature. All three setups use two vector network analyzers; one of them has four test ports and two internal signal sources (equipment operates up to 50 GHz).

The Laboratory of Dielectrics at Department of Chemistry, University of Wroclaw has a microwave system for measurement dielectric specimen in a form of a disc. The RF head used in the system is a core part and its design makes use of experiences gained over a few decades of studies by Prof. Hubert Kolodziej research group. The acceptable specimen thickness is up to 6 mm with a recommendation to have at least 0.6 mm thick sample to keep high measurement accuracy. The specimen fills the RF head and its temperature control subsystem cool or warms the specimen under test with use of liquid gases or gas flames, respectively. So far, the test head can operate up to +180°C (on the lower side temperature can be lowered to -196°C). Going above these limits calls for re-design of the RF head and different use criteria in selection of construction materials (e.g. ceramics instead presently used dielectrics). Heat produced within the modified RF head will have to be dealt with top performing modern heat insulators, but even those we have to use connectors and cables capable to operate at elevated temperatures.

Impedance and radiation pattern measurements at high temperatures will be another major upgrade goal. We plan to implement temperature control of antenna under test with customized heating circuit located on our antenna positioner (turntable). The positioner geometry and parameters allow to mount such a new temperature

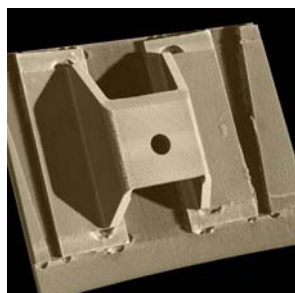
control unit. Radiation pattern measurements will be performed with the near-field scanning system. The system scans near-field samples in the planar-bi-polar and cylindrical format. Furthermore, in a case of impedance measurements we plan to surround an antenna under test with absorbers capable to sustain elevated temperatures. There are commercial pyramidal absorbers operating up to +600°C and we carry on own research on such subject as well.

Computed Tomography for Non-Destructive Inspection of TPS Components

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Institute of Structures and Design, German Aerospace Center (DLR)

Verifying the material quality of a large TPS component belongs to one of the most challenging objectives for non-destructive evaluation techniques. Well known and approved NDE methods such as radiography, ultrasound inspection or lock-in thermography only offer a two-dimensional view of a three-dimensional structure with a projection of all detectable features through the structure's thickness. This gives way to sometimes quite distinct interpretations of microstructural features and defects. However, with X-ray based computed tomography (CT), non-destructive evaluation will be enforced with a powerful tool that provides three-dimensional data with exceptional high-resolution. CT inspections allow the detection of flaws, microcracks, voids, porosity distributions and joining interfaces between different structure components in every part of the structure's volume. In this paper it is shown how the large CT test facility v|tome|x L450 was successfully used for a non-destructive in-situ evaluation of the load introduction attachments of EXPERT's CMC nose cap structure. Image1: X-ray projection of nose cap load introductions; Image 2 & 3: 3D-CT view of the CMC structure components.



Film Cooling Investigation of a Double Wedge Model in Hypersonic Flow

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As an alternative to conventional heat protection systems film cooling could be used, where cooling gas prevents the surface from contact with the hot flow. In contrast to passive TPS, active cooling is potentially suited for cooling local hot spots, which is the subject of this project. In case flaps are used to maneuver a spacecraft, peak heat fluxes occur on the flap due to a reattaching flow behind a separation bubble in the kink region. As a simplified model, a double wedge geometry was chosen for investigation. Experiments were conducted in the shock tunnel TH2 at Mach number 8.35 and a stagnation temperature of 1200 K.

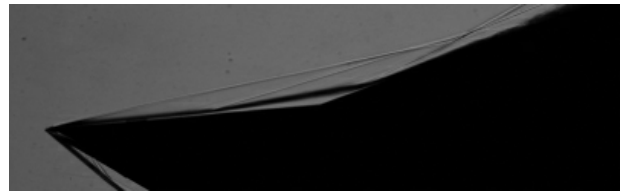


Fig. 1: Schlieren picture of the ramp flow with separation bubble

To reduce the peak heat flux, air was blown out at the reattachment point. Peak heat fluxes could be lowered, as seen in Fig. 2 but relaminarisation has moved downstream and the size of the separation bubble increased, resulting in reduced flap efficiency. Surprisingly, cooling efficiency rises with a decreasing mass flow, this may be due to reduced turbulent mixing.

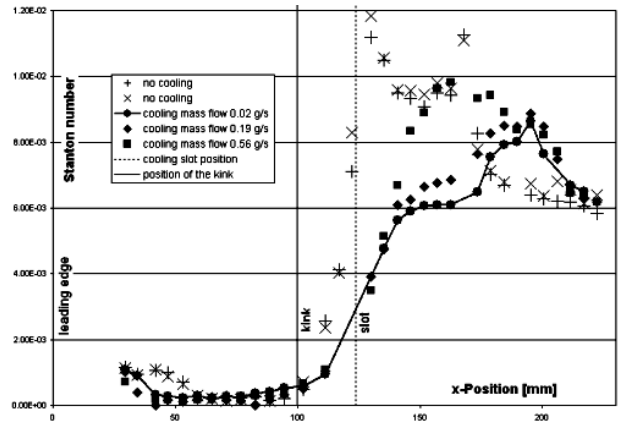


Fig. 2: Stanton number distribution of the model, blowing angle 45°.

UHTC Thermal Sprayed Coating as a TPS for Re-Entry Vehicles

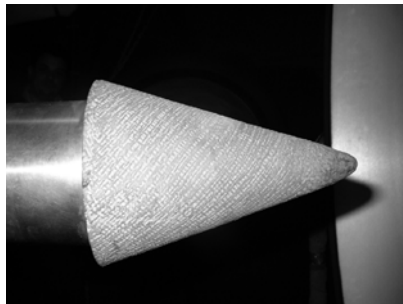
Tului, M.¹; Lionetti, S.¹; Valente, T.²; Pulci, G.²;
Marino, G.³; Gardi, R.³

¹Centro Sviluppo Materiali S.p.A.; ²University of Rome "la Sapienza"; ³CIRA

This paper is a review of the results obtained in a research activity aiming at developing high temperature oxidation resistant thick coatings, deposited by plasma spraying, to be used as TPS. Coating materials were constituted by UHTC; in particular, on a dispersion of SiC and MoSi₂ particles in a ZrB₂ matrix. Laboratory scale characterization, by SEM and XRD, highlight that the coating composition didn't undergo phase transformation during the deposition process. Thermo-physical analysis were performed to determine properties such as diffusivity, thermal expansion and specific heat. Fracture resistance and Young modulus were obtained by means of tensile and four point bending test.

Oxidation resistance was investigated by measuring the oxide scale on flat samples after exposure at high temperatures in air. The study shows that the developed coatings can be utilised as a protection against oxidation up to 2073°K.

To verify laboratory results, the developed coatings were deposited on parts of demonstrative systems (see picture) and successfully tested in PWT with flux conditions simulating orbital re-entry. Results obtained are very encouraging; further studies are in progress.



Analysis and Design of UHTC Hot Structures for Ground and Flight Tests

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University of Naples

The present paper illustrates some of the theoretical, numerical and experimental studies that have been carried out to demonstrate the applicability of Ultra High Temperature Ceramics as hot structures for innovative concepts of thermal protection system.

Arc-jet tests have been carried out on different models with different geometries and materials in different conditions to evaluate the oxidation behaviour of these materials under extreme conditions. Furthermore, the materials response to large heat fluxes is evaluated through the determination of two important parameters, i.e. the emissivity and the catalytic efficiency. In

addition, CFD simulations of the coupled fluid dynamic and thermal fields inside the materials, have been carried out in order to rebuild all the experimental tests and to predict the aerothermal loads during re-entry flights of UHTC test beds, including the UHTC winglet that will fly on the capsule EXPERT, and the UHTC holder that is expected to fly on the FOTON capsule. These flight experiments will have the twofold objective to assess the UHTC ability to withstand the real re-entry environment and to validate the developed aerothermal numerical model.

Modeling Elastic and Thermal Properties of 2.5D Carbon Fiber C/SiC Hybrid Matrix Composites by Homogenization Method

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CTA-IAE

The work presents calculations of elastic constants and thermal properties for 2.5D Carbon Fiber Reinforced Carbon-Silicon Carbide Hybrid Matrix Composite, by using the homogenization technique.

The homogenization technique takes properties of individual components of the composites (fiber and matrix) and characteristics of the geometrical architecture of the preform to perform calculations. Thermostructural composites made with 2.5D preforms are easy to manufacture in relation to 3D ones, are also resistant to thermo cycling and have high resistance to crack propagation in relation to composites made with 2D structures. The calculations were performed by setting total carbon fiber volume fractions of 40%, 45% and 50%, and volume fraction in Z-direction of 2%, 4% and 6%.

Computational Aeroheating Analyses of a Capsule in Martian Atmosphere

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The paper presents an aeroheating analysis of a capsule vehicle entering Mars Atmosphere, aimed to support thermal protection system design studies. The capsule configuration is the axisymmetric blunt cone shown in Fig.1. Computational fluid dynamic analyses have been performed to assess the aerothermal environment around the vehicle in order to evaluate the capsule surface heat flux distributions.

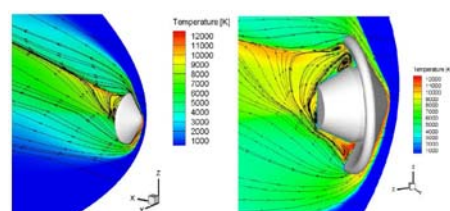


Fig.1 Static temperature contours with streamlines.

The C3NS CIRA code has been used for these computations with a thermo-chemical non equilibrium model suitable for Martian atmosphere. Several numerical computations, both axisymmetric and fully 3D, have been performed in order to obtain heat flux predictions for thermal protection system design scopes. To this purpose, a wide range of flow conditions including reacting and non-reacting flow and different angles of attack have been investigated and compared, both for an elliptic entry and an hyperbolic entry scenario. Moreover, a detailed investigation of non-equilibrium real-gas effects is presented. Some preliminary numerical results are reported in Fig. 1, where the temperature contours together with the stream-traces are shown for a fully 3D computations, considering Mars atmosphere as a perfect gas. For code validation purpose, the available numerical and experimental data of Mars Pathfinder at the entry peak heating conditions have been used. The comparison has shown a good agreement between numerical and experimental data.

Thermal Protection System of the ExoMars Entry Probe

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EADS Astrium Space Transportation*

EADS Astrium Space Transportation is in charge of the development and manufacturing of the Heatshield for the ExoMars Descent Module.

In the continuation to Mars Express, ExoMars is the first Aurora flagship mission to Mars for ESA. With the aim to bring safely a Rover and a Geophysical and Environmental Package (GEP) to the Martian surface in order to study biological environment, the heatshield is a key element to guarantee mission success.

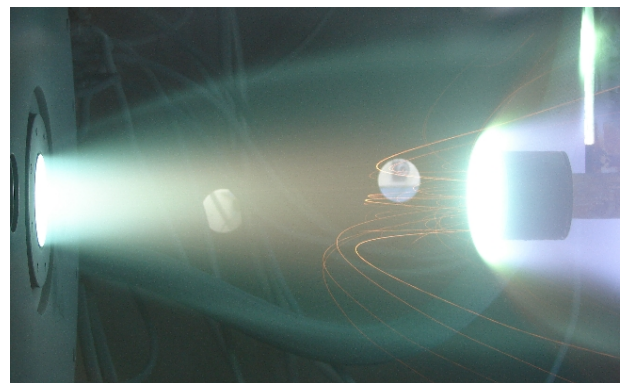
The reference material for the thermal protection system (TPS) of ExoMars is the Norcoat-Liege, a flight proven cork powder and phenolic resin based ablator. The paper will present an overview of the background on this material, as well as the development approach to be carried out for its implementation on ExoMars.

Particle Erosion Tests on an Ablative Material in Martian Atmosphere

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Martian atmosphere is known for heavy dust storms that can develop within several days and lift aerosol particles up to high altitudes. When planning interplanetary missions to Mars with an atmospheric entry the possibility of being exposed to a dust storm must be considered and TPS must be designed to sustain particle

erosion. In 2001, DLR's L2K facility was upgraded for capabilities in Martian atmosphere. A further upgrade was done in 2005 when a first particle injection system had been developed and installed allowing to perform particle erosion tests on TPS materials. In the frame of ESA's MDUST study and the subsequent DUST study under lead of CNES two test campaigns were performed in L2K to investigate the influence of particle erosion on Norcoat Liege material in Martian atmosphere. Tests were carried out at several flow conditions imposing different heat loads on the samples. Particle density, particle size and particle flow rate were other test parameters which were varied systematically. Main test results were the samples' erosion data, i.e. mass loss and surface recession, as well as temperatures measured on surface and backside.



Dust Particle Erosion during Mars Entry

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The ablator Norcoat Liege is baselined as thermal protection material for the European probe EXOMARS planned to land on Mars in 2016. During some Martian years, for unknown reasons, local dust storms may grow to global encircling storms in only a few days. Accordingly, any probe entering directly from a hyperbolic approach has to cope with the risk of flying in a severely dust loaded atmosphere. The dust layer may extend up to 80 km above the terrain. In the frame of two studies in contract to ESTEC and CNES, particle erosion of Norcoat Liege has been investigated. A systematic arc-jet test program supported by trajectory and flow field simulations has been performed. In this paper the results of these investigations are summarized and the influence on heat shield design is assessed.