Aerothermodynamics and Design for Demise (ATD3) Workshop 2021

Thursday, 2 December 2021 - Thursday, 2 December 2021

Virtual Workshop

Programme

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Welcome and Introduction (09:00-09:15)

JAXA SCIENTIFIC RESEARCH: Spectroscopy of a blunted model in a superorbital expansion tube

(09:15-09:40)

- Presenter: TANNO, Hideyuki (Japan Aerospace Exploration Agency Kakuda Space Center)

A spectroscopy test campaign was conducted to observe the emission from the shock layer of a blunted model in an impulsive facility HEK-X[1] in the JAXA Kakuda space center. The HEK-X is a free-piston-driven expansion tube developed for fundamental studies of super-orbital aerothermodynamics, which was designed to produce shock speed up to 14km/s. Applying 'tuned operation,' the facility can operate at driven-pressure up to 130MPa with a comparatively long duration than conventional operation.

For spectroscopy in HEK-X, a simple spectrometer based on a grism (Showa-Kikai VEGA[2]) was developed, which was initially designed as an astronomy observation. Since the emission from the shock layer is extraordinarily strong in HEK-X, an expensive image-intensifier commonly used in the emission spectroscopy was not necessary. The image-sensor size of 2048x2048 of the camera, the spectrometer's resolution is 1.3 nm/pixel with the coverage wavelength from 380nm to 780nm. It has the following features; simple configuration, low cost, and ease of setting up. Since the current facility's test duration is extremely short order of hundred to sub-hundred microseconds, a high-speed video camera (Photron SA-Z.) was adopted to obtain the sequential spectra images with each 5micro seconds.

As a test model, a 10% scale model (40mm diameter) of the Hayabusa-2 sample return capsule was used , which was successfully returned from the deep space asteroid in December 2020. The spectrum of the emission from the shock layer was measured under the shock speed from Vs=6km/s to 10km/s. The spectrometer successfully measured, hydrogen lines around 638nm (H-Alfa) and around 490nm (H-Beta) were clearly identified under the 9km/s condition. An oxygen atom was also recognized at 777nm. In contrast, 590nm sodium and 538nm line suspecting Iron were predominant with diminishing hydrogen lines under the Vs=6km/s condition. In the presentation, the detail of the spectrometer, including calibration, will be described, and measurement uncertainty will be discussed. The spectrum obtained under suborbital speed and super-orbital speed will also be compared to identify the test flow characteristics of HEK-X.

ESA SCIENTIFIC RESEARCH: What to do when re-entry just isn’t hot enough? (09:40-10:05)

- Presenter: SMET, Geert (ESA)

Several D4D techniques are available to achieve a complete spacecraft (equipment) demise. The mass can be minimized or more demisable materials can be selected, the heat flux could be controlled by altering the ballistic coefficient and local geometry of objects or an early fragmentation of the spacecraft and its equipment could be facilitated. If some fragments survive, their impact on the casualty risk can be limited by keeping them together using the containment technique. Even using these techniques, we may not be able to design a sufficiently demisable spacecraft. So what can we do, when it appears that re-entry just isn’t hot enough?

We make it hotter! Using pyrotechnic compositions, e.g. thermite, an exothermic reaction can provide additional energy in order to facilitate demise. These ideas are described in ESA patent EP3604143A1 and CNES patent FR2975080A1. Compared to re-entry, exothermic reactions add a relatively small additional amount of energy. However, the energy can be released where and when it's necessary. This new D4D technique could be used in multiple ways:

- Providing extra energy to undemisable equipment.
- Severing the interface between the spacecraft and equipment.
- Fragmenting equipment in two or more parts.
- Severing secondary mechanical interfaces, e.g. harness, propulsion or heat pipes.
- Combination of several of the above, where for example the interfaces are severed, the equipment is fragmented and additional energy is added to the remaining fragments. This use case requires predetermined sequencing of events, e.g. by using fuses.
- Altering the aerodynamic properties of equipment, e.g. creating a hole in a propellant tank.
- Severing joints in the spacecraft to enable break up, e.g. by introducing energetic materials in the joint or in the spacecraft structural panels surrounding the joint/insert.
- Creating thermo-elastic stresses that lead to fracture or rupture, e.g. for ceramics.

A first effort to prove the concept has yielded mixed results. Thermite ignition in a plasma wind tunnel and release of a significant amount of energy was demonstrated. However, the impact on the demise of the test samples was limited for several reasons:

- Sub-optimal thermite composition
- Insufficient thermite for the test sample
- Issues with test predictions and correlation

• Sub-optimal test set-up, yielding a non-representative temperature distribution
• Complicated test sample
• Impact of the formation of slag
ESA activity ‘Spacecraft demise during re-entry using various exothermic reactions’ has just started to prove the concept, with these objectives:
• Design, optimization and proof of concept by simulation and test at breadboard level in a representative environment of the use of exothermic reactions for demise purposes. The desirability/viability of different use cases needs to be assessed.
• Design and verification of different fuse concepts to provide the energy needed for ignition at various temperatures.
• Devising design guidelines for use of the technology in various equipment.
If developed successfully, using exothermic reactions to facilitate demise could provide a paradigm shift, from trying to design all equipment for demise, to demising existing equipment with minor changes while leveraging existing heritage.

ESA GSTP ACTIVITY: Rebuild and data exploitation of the AVUM re-entry event for break-up model development (10:05-10:30)

- Presenter: DUMON, Jéromine (R.TECH)
These 10 last years, the prediction of the space debris survivability during their re-entry and the associated prospective risk on ground are more and more in the scope of scientific researches.
The 2nd of November 2016, two objects were found in South India: a COPV tank near Dindigul and a titanium tank near Karur. They are fragments from ESA’s AVUM upper stage used on the first qualification flight of the VEGA rocket, launched in 2012, which underwent a destructive uncontrolled re-entry. This incident is also a chance, especially since the detailed orbital observations close to the re-entry epoch are known.
In this context, ESA proposed an activity aimed to rebuild the re-entry trajectory and the break-up sequence. First, HTG and R.TECH are in charge of the numerical rebuild with an industrial spacecraft-oriented tool : SCARAB (HTG) and PAMPERO (R.TECH). This should then allow to calibrate re-entry risk verification tools and procedures. IRS will add structural and material tests in the order to help understanding of break-up sequences.
This communication will present the project in more details and will show preliminary results.

Q&A (10:30-10:40)

Coffee break (10:40-10:55)

ESA GSTP ACTIVITY: Demise of CFRP materials in atmospheric entry conditions (10:55-11:20)

- Presenter: SCHROOYEN, Pierre (Cenaero)
Carbon Fibers Reinforced Polymers (CFRP) are used in the manufacturing of pressurized tanks for satellites or launcher upper stages. These composite materials, usually wrapped around a metallic liner, show a strong resistance to demisability when exposed to high enthalpy flows since they fundamentally behave similarly to ablative Thermal Protection Materials (TPMs). The objective of the ongoing GSTP “ Identification of ablation process in porous materials” is to perform an experimental campaign in the VKI Plasmatron and reproduce it numerically using Cenaero tools. Using this joint numerical-experimental approach, the partners aim to extend high-fidelity models developed for highly porous TPMs and enable demisability prediction of dense CFRPs.
The Plasmatron experiments are conducted on tank-shaped scaled samples inspired from Vega’s Attitude Vernier Upper Module (AVUM) pressurized tank. A first batch of CFRP samples has been tested and the material response reproduced numerically. Notably, the quality of this first batch of manufactured samples was affected by some technological limitations which clearly emerged when trying to downscale the AVUM’s tank maintaining similar manufacturing process and raw materials (e.g. fiber tow). A second batch of samples releasing those constraints is currently being manufactured. The presentation will show an overview of the numerical, modelling and experimental efforts.

ESA GSTP ACTIVITY: Advancements in demisability testing at VKI: Sub- and supersonic experiments of titanium, zerodur and quartz (11:20-11:45)

- Presenter: HELBER, Bernd (von Karman Institute for Fluid Dynamics)
The goal of the ongoing GSTP “Validation of Space Debris Demise Tools using Plasma Wind Tunnel Testing and Numerical Tools” between VKI (prime) and Cenaero is the execution of detailed high-enthalpy demisability experiments in the VKI Plasmatron to support the development of high-fidelity numerical models, from which

improved engineering correlations may be eventually derived.

During the first part of the project, the VKI team intensively tested titanium (grades 2 and 5), quartz, and Zerodur in subsonic plasma conditions. We employed a comprehensive experimental setup, targeting recession of the surface as well as the radiative response of the different materials. For this purpose, we focused several calibrated radiometry instruments (Heitronic radiometer 0.6-39µm, Raytek 2-colour pyrometer 0.75-1.1µm, Optris 1-colour pyrometer 5µm) along with a high-temperature infrared camera (3-5µm) in the stagnation region of the test sample. This allowed us the reconstruction of 3D emissivity-corrected surface-temperature maps of the (possibly receding) material, which could be used for quantitative comparison with the numerical results. The plasma freestream was experimentally characterized using spatially resolved emission spectroscopy along with numerical simulations with our in-house resistive magnetohydrodynamic ICP code.

While Zerodur is a complex lithium-aluminosilicate glass-ceramic, widely used in space applications, basic quartz (SiO2) is helping us to deeply characterize the experimental setup and to understand demise phenomena (melting, evaporation) in the absence of complex oxidation processes. Quartz experiments have been performed below demising temperatures to verify the overall energy balance with numerical models as well as at higher heat loads to demise the material. The experiments have been simulated by VKI using a 1D stagnation-line CFD code coupled to a material solver, as well as by Cenaero through the high-fidelity solver ARGO, with both numerical strategies matching well the measured surface temperatures.
Titanium has been investigated in various atmospheres (air, nitrogen) and heat loads, again highlighting the complex surface chemistry, which should be well understood to achieve a detailed description of the material response. No test condition has been identified for the moment to address solely the melting of the material. Further analysis of the surface products is currently ongoing.

In parallel to the subsonic experiments, three supersonic nozzles have been designed, manufactured, and commissioned in the Plasmatron facility for stagnation-point and flat-plate testing. The capability and test envelope of those nozzles are currently being characterized and we plan to present the first overview of those results at the Workshop.

ACADEMIC SCIENTIFIC RESEARCH: GPU aided 2D high-enthalpy flow solver with state-to-state kinetics

(11:45-12:10)

- Presenter: COLONNA, Gianpiero (PLASMI Lab at CNR-NANOTEC)
To properly account for non-equilibrium in high enthalpy flows, state-to-state (StS) kinetics should be the most reliable, describing internal distributions departing from the Boltzmann. Due to the large dimension of the chemical system, this model requires computational time not affordable on nowadays computers, and most of the applications were limited to 1D geometries [1-3]. In recent years, a 2D fluid dynamic code has been developed including the StS kinetics [4], fully exploiting the multi-GPU computer using CUDA-MPI library [5]. The model has shown its versatility, being applied to the study of the expansion of the Ti plasma plume produced by laser ablation in nitrogen environment.

Recently, the 2D code has been improved to include a detailed catalysis model [6], trying to reproduce recent experimental results, obtained in CIRA for very high enthalpy and very low pressure flow hitting a copper sphere. The finite-rate partial catalysis model provides results that are closer to the experimental ones than those obtained by a fully catalytic approach. Among the different StS catalytic models the outcomes have shown that the surface recombination on only the highest energy level gives more accurate results.

To extend the number of applications the code has been also applied to a high enthalpy flow over a double wedge [7]. Numerical results obtained by the StS model have been compared with those obtained by multi-temperature Park model and those reported by Hao et al [8s]. Results show differences in peak heat flux and in dissociation degree of oxygen, showing the need of StS kinetics also for oblique shocks.

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[4] M. Tuttafesta, G. Colonna, G. Pascazio, Computing unsteady compressible flows using Roe’s flux-difference splitting scheme on GPUs, Computer Physics Communications 184 (6) (2013) 1497–1510

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[7] D. Ninni, F. Bonelli, G. Colonna, G. Pascazio, Unsteady behavior and thermochemical nonequilibrium effects in hypersonic double-wedge flows, submitted to Acta Astronautica.

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INVITED SPEAKER - ACADEMIC SCIENTIFIC RESEARCH: Applying Ground Experiment Findings to the Simulation of Destructive Pressure Vessel Re-entry (12:10-12:35)

- Presenter: PAGAN, Adam S. (Institute of Space Systems, University of Stuttgart)

Pressure Vessels have gained notoriety for being one of the most frequently identified spacecraft debris items recovered on ground following destructive entry events. As such, they constitute a key factor in determining the overall ground risk associated with a given uncontrolled entry event.

Due to their often straightforward physical features as uniformly blunt bodies, spherical pressure vessels in particular lend themselves well to an academic reduction of the re-entry problem, justifying a focus on material-specific heating interfaces and thermo-ablative response behaviours. This is highly convenient towards directly applying the findings of ground-based experiments conducted on the level of material samples to flight-relevant simulation scenarios. As such results can be compared directly with accordingly recovered debris items, mutual verification becomes straightforward between the three cornerstones of inquiry comprising ground testing, computational models, and data from actual destructive entry events.

A brief overview of the key parameters governing the thermo-ablative response behaviour, and by extension the overall demisability and ultimate ground risk associated with these objects is given, followed by a summary of recent findings from Plasma Wind Tunnel (PWT) experiments for materials used in many monolithic and composite-overwrapped pressure vessel designs. Special attention is given to those material parameters governing the heating interface of the object, namely the surface emissivity and its catalytic properties.

A modular definition for an empirical mass-specific heat of ablation is introduced, which can be extracted directly from the results of well-defined PWT material tests. The definition of this empirical heat of ablation can be adjusted based on a) the respective availability of complementary material data such as relevant emissivity datasets and thermophysical properties and b) the fidelity with which the coupled simulation tool represents the aerothermodynamic heating interface and internal heat transport, in any case retaining an optimum in accuracy. Combined with a material-specific temperature threshold, the thermo-ablative response behaviour of any material can thus conveniently be described by two metrics in an empirical and thus quantitatively meaningful fashion, independently from its qualitative nature.

This approach is coupled to a simple entry propagator model optimized for the simulation of thin-walled re-entering spherical bodies, accounting for varying ballistic coefficients and potential tumbling motions, in order to assess three distinct but relevant entry scenarios respectively for three pressure vessel design types defined primarily by their material composition. In the given example, the utilised definition of the effective heat of ablation specifically considers the effects of catalytic recombination and the pressure vessels' thermo-ablative response is evaluated accordingly in all three scenarios under consideration of non-equilibrium effects, demonstrating a use-case in which a fully formed catalysis model is available yet where internal heat transport phenomena are neglected.

A summary of according simulation results is presented and discussed under consideration of the available evidence of relevant recovered spacecraft debris.

Q&A (12:35-12:45)

Lunch break (12:45-13:45)

ESA GSTP ACTIVITY: Numerical and Experimental Validation of Spacecraft Demise during Atmospheric Re-entry (13:45-14:10)

- Presenter: MARTINEZ, Thomas

Reducing the risk of casualties from debris uncontrolled re-entry is of major interest. It requires to advance the knowledge of space debris degradation during their re-entry and to strengthen the predictive capabilities of the

high-fidelity and spacecraft-oriented numerical tools and material response solvers.
Under the present study, various materials have been identified to be analysed and characterised to provide insight into degradation and fragmentation processes and enrich the current ESA ESTIMATE database. Metallic alloys such as Haynes 25 and AISI 304L are characterised at CNRS-PROMES facilities for oxidation kinetics and emissivity analysis. CFRP thermal properties are investigated in ONERA's facilities. Furthermore, plates of previously cited materials and Invar36, are exposed to high-enthalpy plasma flow in shear-stress configuration in the Plasmatron facility at the von Karman Institute to investigate ablation processes in atmospheric re-entry environment.
An explicit coupling strategy of in-house RTech's high-fidelity tool Mistral with material response solver PATO based on OpenFOAM is adopted to rebuild numerically the experiments in the VKI facilities. Material in-depth models developed at Coria are implemented in PATO to compute the degradation of metallic alloys and correlations and simplified models are implemented in spacecraft-oriented PAMPERO tool developed by CNES in collaboration with RTech in order to improve accuracy of the predictions.

ESA/ACADEMIC SCIENTIFIC RESEARCH: A multi-fidelity simulation framework for atmospheric re-entering bodies (14:10-14:35)

- Presenter: MORGADO, Fábio (University of Strathclyde)

Recent data has shown that between 2000 and 2020, the number of objects in orbit around the Earth has increased by approximately 82%, reaching a value close to 20000 objects, from which 53% are fragmentation debris, and the current tendency is for the number of space objects to grow in the forthcoming years. This increase has led to the need for a sustainable use of the space environment, by guaranteeing a safe disposal of the objects launched into orbit. In order to avoid the cluttering of space and decrease the risk of in-orbit collisions, the objects undergo a destructive atmospheric re-entry in a controlled or uncontrolled manner after reaching their end of life, which can trigger the generation of several fragments that need to be tracked. The accurate prediction of this destructive process is an important step to correctly assess the ground impact risks of surviving fragments.

The accurate simulation of a multi-body atmospheric reentry is equivalent to solving a complex multi-physics problem, which is a difficult and time-consuming task. High-fidelity simulations are computationally demanding, even more with the increase of assumptions complexity and increase in the number of fragments during the demise process, making the use of low-fidelity methods appealing. The major drawback of using low-fidelity methods is the high degree of uncertainty risen from the simplified engineering assumptions and the treatment of the objects computational geometry.

To overcome this issue, a multi-fidelity based approach in proposed. A recently developed fully automated framework based on the open source tool FOSTRAD (Free Open Source Tool for Re-entry of Asteroids and Debris) allows the computation of the aerodynamic and aerothermodynamic quantities at the different flow regimes experienced by the bodies during the reentry process (e.g. rarefied, transitional, slip-flow and continuum regime) using local panel inclination method based on the Modified Newtonian Theory. The uncertainty of the results is reduced through the use of an high-fidelity CFD solver when the simplified models uncertainty surpasses the imposed threshold, thus correcting the predictions, and during very sensitive time-windows, such as the moments before and after the breakup of the joints connecting the bodies. The fidelity coupling allows the demise simulation to take into account the influence of the shock-generated flow features and shock impingement in the bodies dynamics and fragmentation. The dynamic motion of the objects is computed using the integrated 6 Degrees Of Freedom (DOF) trajectory propagator, enabling to analyse the individual fragment trajectory. The computational grid required for the high-fidelity CFD simulation is automatically generated using the API calls to the open-source mesh generator *GMSH*. Additionally, to achieve grid convergence, the grid is refined using the anisotropic grid adaptation tool *AMG*.

To test the new framework, a test-case of two spheres connected by a cylindrical beam is conducted, and the results compared with the solution obtained from FOSTRAD. At this first stage, the flow is assumed to be inviscid and the separation of the bodies is considered to occur at a given specific altitude

CNES ACTIVITY: R.Tech numerical simulation tools for debris modeling (14:35-15:00)

- Presenter: SPEL, Martin (R.Tech)

R.Tech is active since 20 years in the field of numerical simulation for aerothermodynamic reentry and is working with the CNES on the problematic of space debris since 10 years. An overview of different tools developed is presented. The combination of high fidelity codes Mistral-CFD in the continuum regime and Mistral-DSMC in the rarefied regime allow to simulate any conditions for a LEO reentry using high fidelity. The process of using high fidelity tools to derive and validate simplified models in both spacecraft oriented (PAMPERO) and object oriented (DEBRISK) tools is presented.

CNES ACTIVITY: Satellite re-entry uncertainty quantification and sensitivity analysis using object-oriented code Debrisk (15:00-15:25)

- Presenter: VAN HAUWAERT, Pierre (RTech Engineering BV)
The French Space Agency CNES in collaboration with R.Tech have developed a probabilistic tool to evaluate the survivability of space debris based on DEBRISK. The uncertainties of all the models are accounted for. Their effect on the survivability is quantified through Monte Carlo method to evaluate its distribution compared with the determinist approach. Two models for simulating the fragmentation of the spacecraft are investigated. The uncertainties of the input parameters are ranked with respect to how much they influence the uncertainties on the survivability. The heat rate, the break up altitude and the low-speed drag coefficient are the parameters with the largest influences on the casualty area, given their uncertainties. The choice of the threshold of maximum energy for an object impacting the earth to be considered a human risk also influence significantly the casualty area.

Q&A (15:25-15:35)

Coffee break (15:35-15:50)

ESA GSTP ACTIVITY: De-Risk of the Development of a High-Speed, High-Accuracy, Multi-Physics Propagator to be used in Design for Demise. (15:50-16:10)

- Presenter: PROBYN-SKOUFA, Michael (Frazer-Nash)
This project addresses aerothermodynamics tools for Design for Demise (D4D) and aims to create a step-change in safer spacecraft development by improving the speed, accuracy, and usability of aerothermal D4D tools. Any new tool developed must not only be sufficiently accurate and generate results at an appropriate rate and cost, but most also be intuitive to use.
The current project, undertaken by a consortium comprising of Frazer-Nash Consultancy, Fluid Gravity Engineering, and Belstead Research, aims to de-risk the development of a new propagator.
This will be done by:
- Establishing the user requirements of such a tool. This is an essential step to ensure that any new tool developed provides maximal value to industrial stakeholders and can provide the required confidence in the results to the regulators.
- Targeting the development of new methods of addressing uncertainty in the existing models. This will be done to demonstrate that any new propagator developed should improve the accuracy of the results, this step aims to de-risk this part of the full activity. This step will investigate the options available to improve the modelling of the physics.

Finally, a specific de-risk activity, demonstrating a new, user-friendly graphical user interface will be generated to allow stakeholders to interact with a ‘mock-up’ of the future propagator tool in order to obtain rapid and valuable feedback to feed into any future full activity, in a truly agile approach.
The consortium chaired a user-requirements workshop with industry stakeholders, regulators, and ESA on 8 November 2021 to elicit the requirements of a new high-speed, high-accuracy, multi-physics propagator. Initial high-level findings from this meeting will be presented at ATD3 along with a brief summary of the current landscape of D4D tools. Frazer-Nash, Fluid Gravity, and Belstead Research, as well as ESA, would greatly welcome any further contribution from industry, regulators, researchers, or other interested parties, on their thoughts on the requirements of future D4D tools.

INNOVATION & TECHNOLOGY: Demisable Pressure Vessels (16:10-16:35)

- Presenter: SARDOU, Max
Our compagnie is involved in composite for 41 years.
We have studied possibility to create demisable pressure vessels for re-entry application.
The proposed pressure vessel uses thermoplastic liner and composite outer shell.
We have selected a composite made of epoxy and fibres for the outer shell.
The peculiar fiber extremely light and strong. its key advantage is that it melts at 130°C.

ACADEMIC SCIENTIFIC RESEARCH: Measurement of the aerodynamic coefficients for basic shapes in the hypersonic flow regime (16:35-17:00)

- Presenter: ESPOSITO, Antonio (University of Naples Federico II)
In the years between 1995 and 2015, dedicated research activities were conducted at the Department of Industrial Engineering of the University of Naples Federico II with the ultimate goal of building a Database of aerodynamic coefficients (CD and CL) for simple-shape bodies (such as spheres, cylinders, cones) in different aerodynamic

conditions (special focus on hypersonic low-density regime). Such activities included (but were not limited to) the measurement of: 1) the compressible subsonic forces on a conical cylinder; 2) the compressible subsonic forces on an AGARD “A” model; 3) the forces acting on a conical cylinder in the supersonic regime; 4) the thrust generated by an arc-jet; 5) the forces acting on a "bluff" cylinder, a hemispherical cylinder, a conical cylinder and a cone with large opening angle in hypersonic low-density conditions; 6) the forces in the supersonic-continuum regime and hypersonic low-density regime for simple geometric shapes, i.e. a cylinder, a sphere, and a "bluff” cone with different length-to-diameter ratios.
In such a framework, and through the combined use of the two distinct (supersonic and hypersonic) facilities, data were obtained sufficient to verify the validity of the well-known Schlichting curve for spherical bodies in the range of Reynolds numbers from about 102 up to about 106.
Additional relevant (technical) information about the test campaign for the hypersonic regime can be summarized as follows. In order to determine the aerodynamic drag of objects with the spherical symmetry, a one-dimensional, strain-gage balance was used (with a full-scale balance capacity of 2 N and an uncertainty of about □ 0.02 N). The obtained data were correlated with the outcomes of numerical simulations conducted using the DS2G software and with other experimental values available in the literature (in particular, the published data used for these comparisons were selected in such a way that the test conditions in terms of free-stream Mach number, M□, were as close as possible to the selected test conditions, Zuppardi and Esposito, 2001).
With regard to the blunt-cone model, the considered test gas was argon with a mass flow rate of 1 g/s. Two values of the arc electrical current were considered, namely, 300 and 400 A (using the so-called Small Planetary Entry Simulator tunnel). Following the same approach undertaken for the sphere, the results were compared both with other available experimental measurements and with the predictions of a Direct Simulation Monte Carlo (DSMC) software. Despite some inconsistencies with respect to other published experimental data, reasonable agreement was obtained with the DSMC results for relatively small angles of attack (the observed mismatch at higher angles being probably due to interference effects, Russo et al., 2008).

References:
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INVITED SPEAKER - NASA SCIENTIFIC RESEARCH: Challenges in Modeling Hollow Objects in the Transition Flow Regime (17:00-17:25)

- Presenter: OSTROM, Christopher L. (NASA)
In NASA’s Object Reentry Survival Analysis Tool (ORSAT), aerodynamic drag and aerothermal heating coefficients are computed for each of the free-molecular, continuum, and transitional flow regimes using analytical and semi-analytical methods. These methods are typically limited to convex, blunt objects (such as spheres) and are applied to other objects such as boxes and cylinders using multiplicative “shape factors” to account for the different behavior.

Previous literature has analyzed the aerodynamic and aerothermodynamic properties of flow around sharp-edged objects like boxes and cylinders in transitional flow, though only those objects with solid external boundaries. However, many reentry objects we have encountered in real spacecraft have been hollow (i.e., with the potential to allow flow through them). We present here preliminary results from analyses performed using the NASA Direct Simulation Monte Carlo (DSMC) Analysis Code (DAC) on hollow cylinders and boxes (with varying wall thickness-diameter ratio).

Q&A (17:25-17:45)

Greetings and Conclusions (17:45-18:00)