Abstract for Specialists’ Meeting AVT-199 /RSM-029 -on Catalytic Gas Surface Interactions

**Influence of Catalysis and Oxidation on Slug Calorimeter Measurements in Arc Jets**

Anuscheh Nawaz*, Dave Driver**, Imelda Terrazas Salinas***

*Anusheh Nawaz, Sierra Lobo Inc., Thermophysics Facilities Branch, NASA Ames Research Center, MS 229-4, Moffett Field, CA  
**Dave Driver, Reacting Flow Environments Branch, NASA Ames Research Center, MS 230-2, Moffett Field, CA  
***Imelda Terrazas Salinas, Thermophysics Facilities Branch, NASA Ames Research Center, MS 229-4, Moffett Field, CA

**Introduction and Motivation**

Arc jet tests play a critical role in the characterization and certification of thermal protection materials and systems (TPS). The results from these arc jet tests feed directly into computational models of material response and aerothermodynamics to predict the performance of the TPS in flight. Thus the precise knowledge of the plasma environment to which the test material is subjected, is invaluable. As one of the environmental parameters, the heat flux is commonly measured. The measured heat flux is used to determine the plasma enthalpy through analytical or computational models.

At NASA Ames Research Center (ARC), slug calorimeters of a geometrically similar body to the test article are routinely used to determine the heat flux. A slug calorimeter is a thermal capacitance–type calorimeter that uses the temperature rise in a thermally insulated slug to determine the heat transfer rate, see Figure 1(left). Current best practices for measuring the heat flux with a slug calorimeter are described in ASTM E457 – 96. Both the calorimeter body and slug are made of Oxygen Free High Conductivity Copper, and are cleaned before each run.

![Figure 1 (left) Example of hemispherical slug calorimeter used to determine heat flux.](https://ntrs.nasa.gov/search.jsp?R=20120016789)  
![Figure 1 (right) Color change of slugs exposed to different arc jet conditions suggests oxidation of copper.](https://ntrs.nasa.gov/search.jsp?R=20120016789)
The enthalpy in plasma can be described as a sum:

\[ h_{\text{plasma}} = \sum_i c_i \left( \Delta h_{f,i} + h_i(T) \right) + \frac{1}{2} v^2 \]

where \( c_i \) mass fraction of the species, \( \Delta h_{f,i} \) is the standard enthalpy of formation, and \( v \) is the velocity of the plasma. The total enthalpy is thus a sum of the chemical enthalpy (dissociation, ionization), the enthalpy related to the temperature of the plasma (rotational, vibrational, translational movement), and the kinetic enthalpy. The catalytic efficiency of the calorimeter surface directly influences the fraction of the chemical enthalpy seen by the sensor. The lower the cataclycity, the smaller the fraction registered. In order to determine plasma enthalpy from heat flux measurements it is thus desirable to either have a fully catalytic sensor surface, or to accurately know the catalytic efficiency of the material.

In the recent past, attention has been drawn to the fact that slugs are frequently discolored, pointing to possible surface oxidation, in particular after high enthalpy arc jet runs – see Figure 1 (right). At high enthalpy conditions, an oxidized slug, with a surface composition of CuO or Cu$_2$O would have a significant impact on the heat flux measured. From literature, pure copper is nearly fully catalytic (\( \gamma \approx 0.1 \)), while copper oxide falls into the range of medium catalytic efficiency (\( \gamma \approx 0.02 \)). Thus the heat flux registered, and the enthalpy derived, would be lower for copper oxide than for pure copper when exposed to the same plasma condition. For material tests, the testing environment in the arc jet is adjusted to meet a required enthalpy. This means that test enthalpies determined from oxidized slugs might be higher than required, since a portion of the enthalpy is not reflected in the heat flux. Material samples would thus potentially be tested at conditions that are higher than necessary.

In order to determine the degree to which arc jet heat flux measurements are influenced by catalytic and oxidation effects a systematic study is being conducted. It aims at answering the following questions:

- Does the surface composition on a copper calorimeter change during a measurement?
- How does the surface composition change?
- When and how fast does the surface composition change?
- Does this change affect the heat flux reading and by how much?
- How does this affect the CFD material response predicted?

And, following these questions:

- Can we avoid surface composition changes during a heat flux measurement, in the interest of having a well-defined measurement?
- Can we recommend best practices for future test?
Methodology
The methodology used will be described thoroughly in the full paper. The following aspects are highlighted here:

XPS analysis
X-ray Photon Spectroscopy (XPS) is used to analyze the surface composition of the slugs before and after plasma exposure. Monochromatic x-rays are irradiated onto the sample surface, resulting in the emission of photoelectrons whose energies are characteristic of the elements within the sampling volume. The measurement depth is between 0 and 70Å. This technique can be coupled with ion sputtering, to determine an upper boundary for the depth of composition change. This analysis service was provided by EAG (Evans Analytical Group).

SiO$_2$ coating of copper slugs
To achieve a low catalytic surface material, while retaining the high conductivity of copper, the copper slug was sputtered with SiO$_2$. In this technique, the solid SiO$_2$ source is bombarded with Argon plasma, which cause it to release and deposit molecular SiO$_2$ onto the strategically placed target material.

Experiment
Tests were performed in the Aerodynamic Heating Facility (AHF) at NASA Ames Research Center with a 46cm diameter nozzle. Calorimeter slugs were systematically exposed to 6MJ/kg, 15MJ/kg and 16 MJ/kg conditions. Post-test analysis was performed using XPS.

The following tests were conducted thus far:
1- Pre-test, aimed at understanding the surface condition before insertion into the plasma
2- AHF 297 Run2, aimed at characterizing the surface of copper slugs after plasma exposure at three conditions. Additionally, a slug was inserted several times to determine the influence of multiple insertions in the same test run. The surface of all slugs was analyzed.
3- AHF 297 Run3, aimed at investigating the difference in heat flux due to other metal surfaces such as Nickel, Gold, Constantan and Platinum. The surface of all materials was analyzed post test.

It is further planned to conduct at least one more test series aimed at understanding the rate at which the copper slug surface oxidizes, as well as investigate the use of other surface materials such as CuO and SiO$_2$.

Results
The preliminary results from this study show oxidation of copper surfaces to Cu2O before run, and to CuO during plasma exposure, even at low heat flux conditions. Further results will be presented in the full paper. In addition, the impact of the catalytic efficiency on computational models will be explored.
References

Research and Technology Agency
BP 25 – 92201 Neuilly-sur-Seine

Applied Vehicle Technology Panel
Tel: + 33 1 55 61 22 87 /85 – Fax: + 33 1 55 61 22 98/99
e-mail: cheynes@rta.nato.int

Preliminary Meeting Announcement and
CALL FOR PAPERS

Specialists’ Meeting AVT-199 /RSM-029 -on

Catalytic Gas Surface Interactions

organized by the Members of the

APPLIED VEHICLE TECHNOLOGY PANEL (AVT)

AVT-199 Programme Committee

to be held at the von Karman Institute, Rhode-St-Genese, Belgium

22-24 October 2012

Contributions and participation are invited from NATO Nations, Japan, Russia and Switzerland

Note: Final date for submission of abstract 15 March 2012

For further details, please consult the following sections regarding
General Scope of the Meeting
Deadlines and Schedule
Procedures
AVT-199 Programme Committee
Abstract Submission Form
General Scope of the Meeting
The Applied Vehicle Technology Panel (AVT) of the Research and Technology Organization (RTO) of NATO is organizing a Specialists’ Meeting entitled “Catalytic Gas Surface Interactions”. The meeting will be open to NATO Nations, Japan, Russia and Switzerland and is to be held at the von Karman Institute for Fluid Dynamics in Rhode-St-Genese, Belgium from 22-24 October, 2012.

The primary objective of this meeting is to develop a coordinated international activity aimed at providing experimental data on gas-surface interactions that can be used to validate numerical models of these processes. The outcome of this meeting will be a roadmap that will define a framework for complementary studies yielding data for a particular surface-catalyzed reaction, based on the strengths of the different participating groups. All aspects of such a study will be addressed, including plasma test facilities, instrumentation, materials, plasma composition, and relevance to NATO missions.

Discussion sessions during the meeting will facilitate discussions between modelers and experimentalists to design a set of coordinated experiments that address all aspects of the coordinated study. Recognizing the overarching limitation of available research funding, discussions will consider existing data and minimum cost efforts to either supplement such data or provide improved measurements. All researchers within this community, from national laboratories, universities, and industry are welcome to participate. Papers from all groups that address these topics are welcome.

Gas-surface interactions such as surface catalysis significantly impact surface heating for both internal and external flows. Catalyzed surface reactions are driven by flow chemistry, and so are of particular importance in the development of hypersonic vehicles, where shock-induced dissociation can lead to significant, non-equilibrium atomic fluxes impinging on wetted surfaces. Moreover, the current use of limiting assumptions rather than physics based models of gas-surface boundary conditions for predicting vehicle or component performance using computational models has been identified as a limitation for current component design tools. Considering that for external flows, surface catalyzed reactions can augment the heat flux by up to a factor of two, the importance of developing better gas-surface interaction models is clear. Experimental data are needed to better characterize gas-surface interactions and thereby inform the development of higher fidelity surface chemistry models. Such data can be acquired using advanced optical diagnostic techniques in plasma test facilities, but no facility has access to all diagnostic techniques. A major objective of this meeting is, therefore, to develop a road map for a coordinated international effort aimed at providing complementary data that can be used to characterize one or more surface-catalyzed reactions for a relevant material/plasma configuration.

Key topics include: 1) gas-surface interaction modeling; 2) ground test facilities and spectroscopic instrumentation capabilities; 3) pre- and post-test material characterization; 4) candidate gas-surface interaction systems for investigation including material source and purity; 5) preliminary surface-catalyzed recombination measurement results; 6) other relevant topics.
Deadlines and Schedule

1 February 2012  
**Distribution of Call for Papers**  
to solicit abstracts from NATO Nations, Japan, Russia and Switzerland  
after: authors to send their abstracts to the Programme Committee (see procedures)

**Abstract Submission deadline**  
15 March 2012  
after: Programme Committee to create the Specialists’ Meeting Programme from received abstracts

**Authors informed of Selection Decision**  
9 April 2012  
Programme Committee to inform selected as well as rejected authors.  
RTA to dispatch authors’ information package to selected authors  
after: selected authors to prepare their papers, presentation and clearances

**Final Agenda Approved by Programme Committee**  
20 April 2012  
Programme Committee to finalise the Programme  
after: RTA to prepare and publish the official Meeting Announcement

**Submission of Advanced copy of US papers to US National Coordinator**  
8 June 2012  
Deadline for US authors to submit their copy of their advance paper to the US National Coordinator (special instructions to be issued with author’s information package

**Electronic Advance Copy of Paper due at RTA**  
17 August 2012  
deadline for all authors to send an advance copy of their full paper to RTA  
after: the Technical Evaluator for the Specialists’ Meeting to review all submitted papers

**Submission of Final Version of all Papers to RTA**  
14 September 2012  
deadline for all authors to send their final papers to RTA  
after: RTA to pre-release all papers on the RTO website making them accessible to all registered participants to the Specialists’ Meeting  
Note that no paper copies will be available at the meeting site

20-24 October 2012  
Specialists’ Meeting held at von Karman Institute, Rhode-St-Genese, Belgium

**Submission of Corrected Manuscripts**  
15 November 2012  
deadline for all papers to be included in the Meeting Proceedings  
after: RTA to edit, prepare, produce Meeting Proceedings which will be made accessible through the RTO website
Procedures

Security Level and Clearance for Presentation

The Specialists’ Meeting classified as “NATO UNCLASSIFIED + Japan, Russia and Switzerland (open to citizens of NATO Nations, Japan, Russia and Switzerland only). The distribution of the papers will be NATO UNCLASSIFIED + Japan, Russia and Switzerland. For the full overview of NATO Nations please consult the section on NATO Nations Overview.

It is the responsibility of each contributor to fulfill the publication release requirements of his/her organization/company and country and to obtain clearance of abstracts and full papers as needed. An official clearance is mandatory in the United States and there may also be a requirement in other countries to obtain clearance for unclassified abstracts and full papers. For further information, authors should consult the appropriate Programme Committee Member listed in this document or the Co-Chairs.

Invitation and Format of Abstracts

- The initial abstract should describe (in 1000 to 1500 words), the aim, results and conclusions of the work. Inclusion of 1 to 2 figures and/or photographs to support the abstract is encouraged. All abstracts should be submitted by e-mail to the Programme Committee Co-Chairs identified below.

- The full paper (approximately 12 pages) will be requested once the Programme Committee has developed the final agenda for the Symposium.

- Both the abstracts and the full paper must also contain a declaration from the author(s) that there are no restrictions regarding presentation neither during the Symposium nor of the publication in the Meeting Proceedings. Authors’ names, complete mailing addresses and other requested information must be included with the abstracts. Please use the Abstract Submittal Form (Attachment 1) and keep the size of files less than 2 MB.

Programme Committee Co-Chairs
Prof. Douglas G. Fletcher
douglas.fletcher@uvm.edu

Dr. Georg Herdrich
herdrich@irs.uni-stuttgart.de

Prof. T. Schwartzentruber
schwartz@aem.umn.edu
Paper Preparation and Procedure

Authors of papers selected for presentation and publication will be notified by the Programme Committee. The AVT Executive office at RTA will then send detailed instructions concerning the preparation of manuscripts to lead authors. Questions related to technical aspects of the program or the papers should be addressed to the Technical Committee Chairmen as indicated above. Questions of an administrative nature should be addressed to the AVT Executive Office

RTA/AVT Executive Office
Attn: Sandra Cheyne
BP 25
92201 Neuilly sur Seine – Cedex, France
Tel : +33 1 55 61 22 87
e-mail : cheynes@rt.a.nato.int

The special procedure for papers submitted by US authors will be explained in the author’s package.
The NATO RESEARCH AND TECHNOLOGY ORGANISATION

The NATO RESEARCH AND TECHNOLOGY ORGANISATION (RTO) promotes and conducts co-operative scientific research and exchange of technical information amongst NATO nations and NATO partners. The largest such collaborative body in the world, the RTO encompasses over 3000 scientists and engineers addressing the complete scope of defence technologies and operational domains. This effort is supported by an executive agency, the Research and Technology Agency (RTA), which facilitates the collaboration by organising a wide range of studies, workshops, symposia, and other forums in which researchers can meet and exchange knowledge.

For further information, please consult the RTO web site.

Representing one of the technical domains within RTO, the APPLIED VEHICLE TECHNOLOGY PANEL (AVT) strives to improve the performance, affordability, and safety of vehicles through the advancement of appropriate technologies. The Panel addresses vehicle platforms, propulsion and power systems operating in all environments (land, sea, air, and space), for both new and ageing systems.

Further details are given on the AVT web site:

The RTO and AVT websites provide a wide variety of information and on-line services ranging from overview information on the organization’s mission to news regarding upcoming events. You will find on-line access to more than 300 scientific publications as well as information on current activities.

For further assistance do not hesitate to contact the AVT Executive Office
AVT-199 PROGRAMME COMMITTEE

Co Chairs
Prof. Douglas G. Fletcher  
University of Vermont  
Mechanical Engineering  
201 Votey Hall, 33 Colchester Ave  
Burlington VT 05405, United States  
email: douglas.fletcher@uvm.edu

Dr. G. Herdrich  
Institute of Space Systems (IRS)  
University of Stuttgart, Pfaffenwaldring 31  
70569 Stuttgart, Germany  
email: herdrich@irs.uni-stuttgart.de

Prof. T. Schwartzentruber  
University of Minnesota  
110 Union St. SE, Minneapolis, MN 55455  
United States  
email: schwartz@aem.umn.edu

Members

Belgium  
Assoc. Prof. O. Chazot  
VKI  
Chaussee de Waterloo, 72  
B-1640 Rhode St Genese  
email: Chazot@vki.ac.be

France  
Mme M. Balat-Pichelin  
Laboratoire Precedes  
Materiaux et Energie Solaire  
PROMES-SNRS  
UPR 8521, rue du four solaire  
66120 Fort Romeu Odeillo  
balat@promes.cnrs.fr

Mr. F. Sourgen  
ONERA  
BP 74025 - 2 avenue Edouard Belin,  
31055 TOULOUSE cedex 4  
email: Frederic.sourgen@onera.fr

Mr. J-L. Verant  
ONERA  
2, avenue E. Belin  
31055 Toulouse Cedex  
email: verant@onecert.fr

Germany  
Dr-Ing. M.K. Fertig  
German Aerospace Center  
Lilienthalplatz 7  
D-38108 Braunschweig  
email: markus.gertig@dlr.de

Dr. Ing. A. Guelhan  
German Aerospace Center  
Linder Hoehe  
D-51147 Cologne  
email: ali.guelhan@dlr.de
Italy
Prof. C. Bruno
Universita degli Studi di Roma
La Sapienza, Dipartimento Meccanica
Aeronautica
Via Eudossiana, 18, 00184 ROMA
email: cbruno@dma.ing.uniroma1.it

Mr. M. Capitelli
Universita di Bari
Dept. of Chemistry
Campus Universitario
70124 Bari
email: mario.capitelli@ba.imip.cnr.it

The Netherlands
Dipl.-Ing. J. Thoemel
ESA/AOES
Keplerlaan 1
2001 AZ Noordwijk
email: jan.thoemel@esa.int

Dr. L. Walpot
AOES Group-B.V.
Haagse Schouwweg 6G
2332 KG Leiden
email: lwalpot@aoes.com

United States
Dr. D. Bose
NASA Ames Research Center
MS: 230-3, NASA Ames Res. Ctr.,
Moffett Field, CA 94035,
email: dbose@mail.arc.nasa.gov

Prof. I. Boyd
University of Michigan
Department of Aerospace Engineering
1320 Beal Avenue,
Ann Arbor MI 48109-2140
email: ianboyd@umich.edu

Dr. M. Maclean
CUBRC
LENS Aerosciences
4455 Genesee Street
Buffalo, NY 14225
email: maclean@cubrc.org

Mr. J. Marschall
SRI International
Molecular Physics Laboratory,
333 Ravenswood Avenue
Menlo Park, CA 94025
email: jochen.marchall@sri.com
## Overview of NATO Nations

<table>
<thead>
<tr>
<th>Country</th>
<th>Code</th>
<th>Country</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albania</td>
<td>ALB</td>
<td>Lithuania</td>
<td>LTU</td>
</tr>
<tr>
<td>Belgium</td>
<td>BEL</td>
<td>Luxembourg*</td>
<td>LUX</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>BGR</td>
<td>The Netherlands</td>
<td>NLD</td>
</tr>
<tr>
<td>Canada</td>
<td>CAN</td>
<td>Norway</td>
<td>NOR</td>
</tr>
<tr>
<td>Croatia</td>
<td>HRV</td>
<td>Poland</td>
<td>POL</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>CZE</td>
<td>Portugal</td>
<td>PRT</td>
</tr>
<tr>
<td>Denmark</td>
<td>DNK</td>
<td>Romania</td>
<td>ROM</td>
</tr>
<tr>
<td>Estonia</td>
<td>EST</td>
<td>Slovak Republic</td>
<td>SVK</td>
</tr>
<tr>
<td>France</td>
<td>FRA</td>
<td>Slovenia</td>
<td>SVN</td>
</tr>
<tr>
<td>Germany</td>
<td>DEU</td>
<td>Spain</td>
<td>ESP</td>
</tr>
<tr>
<td>Greece</td>
<td>GRC</td>
<td>Turkey</td>
<td>TUR</td>
</tr>
<tr>
<td>Hungary</td>
<td>HUN</td>
<td>United Kingdom</td>
<td>GBR</td>
</tr>
<tr>
<td>Iceland*</td>
<td>ISL</td>
<td>United States</td>
<td>USA</td>
</tr>
<tr>
<td>Italy</td>
<td>ITA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>LVA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Iceland and Luxembourg are NATO members, but currently do not participate in the RTO framework.
Attachment 1

AVT ABSTRACT SUBMISSION FORM

SUBJECT: AVT-199/RSM-029 Catalytic Gas Surface Interactions

(NATO Unclassified+Japan+Russia+Switzerland = releasable to these Nations only)

Authors/co-authors listed in the order they will appear on final manuscript with forenames or initials, and titles, e.g. Dr., Prof., etc.

1. Title Name Nationality _____________________________________________________________

Affiliation: ________________________________________________________________

Full Mailing Address: _________________________________________________________

Tel/fax/email: ________________________________________________________________

2. Title Name Nationality

Affiliation: ________________________________________________________________

Full Mailing Address: _________________________________________________________

Tel/fax/email: ________________________________________________________________

3. Title Name Nationality

Affiliation: ________________________________________________________________

Full Mailing Address: _________________________________________________________

Tel/fax/email: ________________________________________________________________
It will be possible to present the paper at the Symposium and to have it published and distributed to NATO Nations, Japan, Russia and Switzerland.

Name of submitting author and date of submission