

# **46th AIAA Thermophysics Conference 2016**

Held at the AIAA Aviation Forum 2016

Washington, D.C., USA  
13 - 17 June 2016

Volume 1 of 2

ISBN: 978-1-5108-2736-3

**Printed from e-media with permission by:**

Curran Associates, Inc.  
57 Morehouse Lane  
Red Hook, NY 12571



**Some format issues inherent in the e-media version may also appear in this print version.**

The contents of this work are copyrighted and additional reproduction in whole or in part are expressly prohibited without the prior written permission of the Publisher or copyright holder. The resale of the entire proceeding as received from CURRAN is permitted.

For reprint permission, please contact AIAA's Business Manager, Technical Papers. Contact by phone at 703-264-7500; fax at 703-264-7551 or by mail at 34922 Uwptkug'Xcmg{ 'F tkxg."Uwkug"422, Reston, VA 20191, USA.

# TABLE OF CONTENTS

## VOLUME 1

### TP-01: ABLATION I

<b>Gas-Surface Interactions of High-temperature Materials Under High-Enthalpy Flows Using Plasma Wind Tunnels (AIAA 2016-3230)</b> .....	1
<i>Bartomeu Massuti-Ballester, Georg H. Herdrich</i>	
<b>Expansion Tunnel Ablation Testing in Venus Entry Conditions (AIAA 2016-3231)</b> .....	19
<i>Nikhil Banerji, Penelope Leyland, Richard G. Morgan</i>	
<b>Electromagnetic Wave Transmission through Lightweight Carbon Phenolic Ablator: Microwave to Infrared Frequencies (AIAA 2016-3232)</b> .....	31
<i>Martin F. Eberhart, Stefan Loehle, Fabian Zander, Hannes Merbold, Axel Murk, Stefan Merli</i>	
<b>Characterization of Ablation Product Radiation Signatures of PICa and FiberForm (AIAA 2016-3233)</b> .....	39
<i>Michael Winter, Bradley Butler, Paul M. Daney, Scott Splinter, Zhaojin Diao, Francesco Panerai, Alexandre Martin, Sean Bailey</i>	
<b>The ESA ARC Project: Ablation Radiation Coupling for Hypervelocity Re-Entry with Low Density Type Ablators (AIAA 2016-3234)</b> .....	56
<i>Penelope Leyland, Umar Sheikh, Basil Duval, Tobias A. Hermann, Stefan Loehle, Timothy McIntyre, Richard G. Morgan, Han Wei, Jean-Marc Bouilly, Lionel Marraffa</i>	
<b>Investigation of Pyrolysis Gas Chemistry in an Inductively Coupled Plasma Facility (AIAA 2016-3235)</b> .....	72
<i>Corey Tillson, Jurgen Uhl, Jason M. Meyers, Douglas G. Fletcher</i>	

### TP-02: ABLATION II - MODELING

<b>Two-Dimensional Modeling of Ablation and Pyrolysis with Application to Rocket Nozzles (AIAA 2016-3383)</b> .....	93
<i>Peter G. Cross, Iain D. Boyd</i>	
<b>Inverse Heat Conduction Methods in the CHAR Code for Aero thermal Flight Data Reconstruction (AIAA 2016-3384)</b> .....	120
<i>Brandon Oliver, Adam J. Amar</i>	
<b>Overview of the CHarring Ablator Response (CHAR) Code (AIAA 2016-3385)</b> .....	159
<i>Adam J. Amar, Brandon Oliver, Benjamin Kirk, Giovanni Salazar, Justin Droba</i>	
<b>Tangle-free Finite Element Mesh Motion for Ablation Problems (AIAA 2016-3386)</b> .....	196
<i>Justin Droba</i>	
<b>Advanced Parallelization Strategies for Modelling Flow Through Ablative Thermal Protection Systems (AIAA 2016-3387)</b> .....	260
<i>Revathi Jambunathan, Deborah A. Levin</i>	
<b>Development and Verification of Enclosure Radiation Capabilities in the CHarring Ablator Response (CHAR) Code (AIAA 2016-3388)</b> .....	290
<i>Giovanni Salazar, Justin Droba, Brandon Oliver, Adam J. Amar</i>	

### TP-03: REENTRY SYSTEMS AND INSTRUMENTATION

<b>Experimental and Computational Fluid Dynamics Studies of Superorbital Earth Re-entry (AIAA 2016-3532)</b> .....	333
<i>Elise Fahy, David Buttsworth, Rowan Gollan, Peter Jacobs, Richard G. Morgan</i>	
<b>Flight Experiment Verification of Shuttle Boundary Layer Transition Prediction Tool (AIAA 2016-3533)</b> .....	347
<i>Scott A. Berry, Karen Berger, Thomas J. Horvath, William A. Wood</i>	
<b>Assessment of Fencing on the Orion Heatshield (AIAA 2016-3534)</b> .....	363
<i>Antonella Alunni, Tahir Gokcen</i>	
<b>Uncertainty Analysis of Thermal Protection System Response of a Hypersonic Inflatable Aerodynamic Decelerator (AIAA 2016-3535)</b> .....	378
<i>Andrew J. Brune, Serhat Hosder, Karl T. Edquist, Steven Tobin</i>	

<b>Mars 2020 Entry, Descent, and Landing Instrumentation (MEDLI2) (AIAA 2016-3536)</b> .....	399
<i>Helen Hwang, Deepak Bose, Henry Wright, Todd R. White, Mark Schoenenberger, Jose Santos, Chris D. Karlgaard, Chris Kuhl, Tomo Oishi, Dominic Trombetta, Milad Mahzari, Steven P. Pennington</i>	

## **TP-05: RADIATION**

<b>Non-equilibrium Radiation for Earth Entry (AIAA 2016-3690)</b> .....	412
<i>Aaron M. Brandis, Christopher O. Johnston, Brett A. Cruden</i>	
<b>Echelle Spectroscopy for High Enthalpy Flow Diagnostics (AIAA 2016-3691)</b> .....	431
<i>Stefan Loehle, Tobias A. Hermann, Fabian Zander, Thomas Marynowski</i>	
<b>Characterization of High-Enthalpy and Non-Equilibrium Flows Using Laser Absorption Spectroscopy (AIAA 2016-3692)</b> .....	439
<i>Tobias S. Mayer, Bartomeu Massuti-Ballester, Georg H. Herdrich, Stefanos Fasoulas</i>	
<b>Refinements to Afterbody Radiative Heating Simulations for Earth Entry (AIAA 2016-3693)</b> .....	448
<i>Christopher O. Johnston, Marco Panesi</i>	
<b>A Tunable Laser Absorption Diagnostic for Measurements of CO in Shock-Heated Gases (AIAA 2016-3694)</b> .....	467
<i>Megan MacDonald, Brett A. Cruden</i>	
<b>A Reduced Order Maximum Entropy Model for Chemical and Thermal Non-equilibrium in High Temperature CO<sub>2</sub> Gas (AIAA 2016-3695)</b> .....	479
<i>Amal Sahai, Bruno E. Lopez, Christopher O. Johnston, Marco Panesi</i>	

## **TP-06: SPECIAL SESSION: SPACECRAFT THERMAL MANAGEMENT**

<b>Thermal Enhancements for Separable Thermal Mechanical Interfaces (AIAA 2016-3696)</b> .....	494
<i>Matthew D. Flannery, James Schmidt, Jens Weyant, Kevin Thorson</i>	
<b>An Advanced Card Lock for Space and Terrestrial Applications (AIAA 2016-3697)</b> .....	502
<i>Nicholas Kattamis, Jay C. Rozzi</i>	
<b>Reduced-Order Modeling for Rapid Thermal Analysis and Evaluation of Spacecraft (AIAA 2016-3698)</b> .....	510
<i>Derek W. Hengeveld</i>	
<b>Single-Sided Guarded Hot Plate Method for Comparative Testing of Thermal Radiation Barriers in Vacuum (AIAA 2016-3699)</b> .....	522
<i>Kevin W. Irick, Derek W. Hengeveld</i>	
<b>Enabling Future Spacecraft Missions through Isothermal Bus Thermal Management (AIAA 2016-3700)</b> .....	535
<i>Derek W. Hengeveld, Andrew D. Williams, Brent S. Taft</i>	
<b>Development of the Two Phase Flow Separator Experiment for a Reduced Gravity Aircraft Flight(AIAA 2016-3701)</b> .....	547
<i>Eric Golligher, Daniel J. Gotti, Kelly M. Gilkey, Jay Owens, Nang Pham, Philip Stehno</i>	
<b>Thermal Control of a Gravitational Reference Sensor (AIAA 2016-3702)</b> .....	555
<i>Abdulrahman S. Alfauwaz, Faisal Alamri, Andreas Zoellner, Abdulaziz Alhussain, Suwen Wang, Shailendra Saraf, Sasha Buchman, John Lipa, Daniel DeBra</i>	

## **TP-07: ADVANCED MODELING I - DSMC**

<b>State-to-State Vibrational Energy Modeling in DSMC using Quasiclassical Trajectory Calculations for O + O<sub>2</sub> (AIAA 2016-3839)</b> .....	562
<i>Taiyo Wilson, Kelly A. Stephani</i>	
<b>DSMC Shock Simulation of Saturn Entry Probe Conditions (AIAA 2016-3840)</b> .....	576
<i>Kyle J. Higdon, Brett A. Cruden, Aaron M. Brandis, Derek S. Liechty, David B. Goldstein, Philip L. Varghese</i>	
<b>Heat Flux and Drag Correlations for High Speed Flight at any Knudsen Number (AIAA 2016-3841)</b> .....	596
<i>Narendra Singh, Thomas E. Schwartzenruber</i>	
<b>Finite-rate Oxidation Model for Carbon Surfaces from Molecular Beam Experiments (AIAA 2016-3842)</b> .....	608
<i>Savio J. Poovathingal, Thomas E. Schwartzenruber, Vanessa Murray, Timothy K. Minton, Graham V. Candler</i>	
<b>Reducing Statistical Scatter in DSMC Solutions of Hypersonic Ionizing Flows (AIAA 2016-3843)</b> .....	631
<i>Carolyn R. Kaplan, Elaine Oran, Utkarsh Aggarwal</i>	

## VOLUME 2

<b>Adapting Vibrational Relaxation Models in DSMC and CFD to Ab-initio Calculations (AIAA 2016-3844)</b> .....	641
<i>Marat F. Kulakhmetov, Israel B. Sebastiao, Alina Alexeenko</i>	

### **TP-08: ADVANCED MODELING II – HYPERSONIC FLOWS**

<b>Vibrational Relaxation and Dissociation in O<sub>2</sub>-O Mixtures (AIAA 2016-4021)</b> .....	657
<i>Daniil Andrienko, Iain D. Boyd, Kevin Neitzel</i>	
<b>Radiative Gas Dynamics of Apollo Command Modules at Angles of Attack (AIAA 2016-4022)</b> .....	680
<i>Sergey Surzhikov</i>	
<b>Thermochemical Nonequilibrium Modeling for Hypersonic Flows Containing Oxygen (AIAA 2016-4023)</b> .....	707
<i>Kevin Neitzel, Daniil Andrienko, Iain D. Boyd</i>	
<b>Adaptive State Resolved Vibrational Energy Modeling for Hypersonic Flow Simulation (AIAA 2016-4024)</b> .....	724
<i>Jonathan M. Burt, Eswar Josyula</i>	
<b>SPARK: A Software Package for Aerodynamics, Radiation and Kinetics (AIAA 2016-4025)</b> .....	743
<i>Bruno Lopez, Mario Lino Da Silva</i>	

### **TP-09: SPECIAL SESSION: THERMAL MANAGEMENT SYSTEMS**

<b>Performance of a Loop Heat Pipe Subjected to a Phase-Coupled Heat Input to an Acceleration Field (AIAA 2016-4145)</b> .....	762
<i>Kirk L. Yerkes, James Scofield, David Courson</i>	
<b>Nonlinear Dynamics in Loop Heat Pipe Operation (AIAA 2016-4147)</b> .....	776
<i>Triem T. Hoang, Robert W. Baldauff, Timothy Holman, Jesse R. Maxwell</i>	
<b>Two Phase Thermal Protection of the Hypersonic Leading Edge (AIAA 2016-4149)</b> .....	787
<i>Jesse R. Maxwell, Triem T. Hoang, Robert W. Baldauff</i>	
<b>High Fidelity Modeling of Energy Transfer in the N<sub>2</sub> + N system for Strong Shock Conditions (AIAA 2016-4150)</b> .....	808
<i>Tong Zhu, Zheng Li, Deborah A. Levin</i>	

### **TP-10: HIGH ENTHALPY GROUND TESTING**

<b>Blunt-Body Heating and Pressure Database from High-Enthalpy, CO<sub>2</sub> Testing in an Expansion Tunnel (AIAA 2016-4151)</b> .....	840
<i>Brian R. Hollis, Dinesh K. Prabhu, Matthew G. MacLean, Aaron Dufrene</i>	
<b>Operational Envelope of the Low Power Plasma Facilities at the University of Kentucky (AIAA 2016-4152)</b> .....	875
<i>Helmut Koch, Bradley Butler, Michael Winter, Christian Arnold</i>	
<b>Flow Characterization Studies of the 10-MW TP3 Arc-Jet Facility: Probe Sweeps (AIAA 2016-4153)</b> .....	905
<i>Tahir Gokcen, Antonella Alunni</i>	
<b>Experimental Thermal Response and Demisability Investigations on five Aerospace Structure Materials under Simulated Destructive Re-Entry Conditions (AIAA 2016-4154)</b> .....	929
<i>Adam S. Pagan, Bartomeu Massuti-Ballester, Georg H. Herdrich</i>	
<b>Analysis and Rebuilding of Experiments on a heated carbon graphite model in the X2 expansion tube (AIAA 2016-4155)</b> .....	943
<i>Jeremy Mora-Monteros, Penelope Leyland, Gwael Hannema, Umar Sheikh, Elise Fahy, Richard G. Morgan, Timothy McIntyre</i>	
<b>High-Pressure H<sub>2</sub>/He/O<sub>2</sub> Combustion Experiments for the Design of the ESTHER Shock-Tube Driver (AIAA 2016-4156)</b> .....	952
<i>Mario Lino Da Silva, Bernardo Carvalho, A. Smith, L. Marraffa</i>	

## **TP-11: THERMOPHYSICS**

<b>Fluid Flow Through Tree-Like Networks of Varying Scale (AIAA 2016-4310)</b> .....	966
<i>David Calamas, Liza T. Zamora, Daniel Dannelley</i>	
<b>PLIF Experiments on Evaporating Isolated Droplet and Droplets Array (AIAA 2016-4311)</b> .....	977
<i>Hafiz Laiq-ur Rehman, Abdelouahab Mohammed-Taifour, Julien Weiss, Patrice Seers</i>	
<b>Analysis of Opportunities for Comparing Models of Effective Thermal Conductivity (AIAA 2016-4312)</b> .....	988
<i>Rafal Wyczolkowski, Henryk Radomiak, Tomasz Wylecial</i>	
<b>Numerical Study on Heat Transfer in Aeronautical Systems by CHT Methods (AIAA 2016-4313)</b> .....	1010
<i>Antonio Carozza</i>	
<b>Influences of Multi-Temperature Models on the Shock Structures of Weakly Ionized Hypersonic Flows (AIAA 2016-4314)</b> .....	1024
<i>Pratibha Raghunandan, Stephen M. Ruffin</i>	

## **TP-12: ADVANCED MODELING III – DNS AND STATE TO STATE**

<b>Rovibrational Grouping for N<sub>2</sub>(<sup>1</sup>S<sub>g</sub><sup>+</sup>)-N<sub>2</sub>(<sup>1</sup>S<sub>g</sub><sup>+</sup>) Energy Transfer using State-to-state Model (AIAA 2016-4315)</b> .....	1036
<i>Robyn L. Macdonald, Alessandro Munafò, Marco Panesi</i>	
<b>State-to-State Kinetic Modeling of Oxygen in Hypersonic Nonequilibrium Flows (AIAA 2016-4316)</b> .....	1048
<i>Eswar Josyula, Jonathan M. Burt, Vincenzo Laporta, Prakash Vedula</i>	
<b>Role of High Fidelity Nonequilibrium Modeling in Laminar and Turbulent Flows for High Speed ISR Missions (AIAA 2016-4317)</b> .....	1069
<i>Konstantinos Vogiatzis, Eswar Josyula, Prakash Vedula</i>	
<b>A Coupled Vibration-Dissociation Model for Nitrogen from Direct Molecular Simulation (AIAA 2016-4318)</b> .....	1087
<i>Narendra Singh, Paolo Valentini, Thomas E. Schwartzentruber</i>	
<b>Analysis of Dissociation and Internal Energy Transfer in High-Energy N<sub>2</sub>+O<sub>2</sub> Collisions using the Quasiclassical Trajectory Method (AIAA 2016-4319)</b> .....	1104
<i>Ross S. Chaudhry, Jason D. Bender, Paolo Valentini, Thomas E. Schwartzentruber, Graham V. Candler</i>	

## **TP-13: HEAT TRANSFER IN AEROSPACE APPLICATIONS**

<b>Comparison of Heat Flux Gages for High Enthalpy Flows - NASA Ames and IRS (AIAA 2016-4422)</b> .....	1123
<i>Stefan Loehle, Anuscheh Nawaz, Georg H. Herdrich, Stefanos Fasoulas, Ed Martinez, George Raiche</i>	
<b>Blockage-Ratio Effect of a Bluff-Body Stabilized Flame on Aerosol Behavior of Carbonaceous (Soot) Nano-PM in a Combustor Burning Jet Propulsion Fuel (AIAA 2016-4423)</b> .....	1134
<i>Masoud Darbandi, Majid Ghafourizadeh, G E. Schneider</i>	
<b>A Mini-Scale Primary-Air Injector Mass-Flow-Rate Effect on Soot Nano-Aerosol Formation in a JP-Fueled Gas-Turbine Combustor (AIAA 2016-4424)</b> .....	1142
<i>Masoud Darbandi, Majid Ghafourizadeh, G E. Schneider</i>	
<b>Investigation of Nose Cone Electrothermal Anti-icing Control Law (AIAA 2016-4426)</b> .....	1148
<i>Liang Ding, Shinan Chang, Shiyu Yang, Mengyao Leng</i>	
<b>Exploring Mechanisms of Particle Size Effects of Iron Oxide on Thermal Behaviors and Combustion Characteristics for 5AT/Sr(NO<sub>3</sub>)<sub>2</sub> Propellant (AIAA 2016-4427)</b> .....	1157
<i>Dan Zhang, Song Lu, Heping Zhang</i>	
<b>Aerodynamic Heating Prediction Tool for a Supersonic Vehicle for Conceptual Design Phase (AIAA 2016-4428)</b> .....	1169
<i>Bugra Simsek, Bayindir Kuran, Mehmet Ali Ak, Sitki Uslu</i>	

## **TP-14: ADVANCED MODELING IV**

<b>Rarefaction Effects for the Transonic Airfoils in Low Reynolds Number Regime (AIAA 2016-4429)</b> .....	1185
<i>Cem Pekardan, Alina Alexeenko</i>	
<b>Inviscid-flow Approximation of Radiative Ablation of Cometary Meteoroids (AIAA 2016-4430)</b> .....	1201
<i>Chul Park</i>	
<b>Improved Non-Boltzmann Modeling for Nitrogen Atoms (AIAA 2016-4431)</b> .....	1218
<i>Bruno E. Lopez, Christopher O. Johnston, Marco Panesi</i>	

<b>Application of A New Thermal-Mechanical Coupling Solver for Ablation (AIAA 2016-4432)</b>	1239
<i>Rui Fu, Haoyue Weng, Jonathan Wenk, Alexandre Martin</i>	
<b>Modeling of Electron Transpiration Cooling for Hypersonic Vehicles (AIAA 2016-4433)</b>	1253
<i>Kyle M. Hanquist, Kentaro Hara, Iain D. Boyd</i>	
<b>Assessment of Continuum Breakdown for High-speed Chemically Reacting Wake Flows (AIAA 2016-4434)</b>	1265
<i>Sharanya Subramaniam, Krishnan Swaminathan Gopalan, Kelly A. Stephani</i>	
<b>Extension of Kestrel to General Thermochemical Models, Part I (AIAA 2016-4435)</b>	1286
<i>Ryan B. Bond, Robert Nichols, Greg D. Power</i>	
<b>Author Index</b>	