NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

HEADQUARTERS

SPACE TECHNOLOGY MISSION DIRECTORATE

300 E. Street, SW

Washington, DC 20546-0001

GAME CHANGING DEVELOPMENT PROGRAM,

POTENTIAL INDUSTRY/NASA PARTNERSHIP IN THE DEVELOPMENT AND ASSESSMENT OF HIGH PERFORMANCE THERMAL PROTECTION SYSTEM MATERIALS

NNH15ZOA005L

Request for Information Issued: *March 2, 2015*

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Potential Industry/NASA Partnership in The Development and Assessment of High Performance Thermal Protection System Materials

Responders are reminded:

REQUEST FOR INFORMATION (RFI): THIS IS *NOT* A REQUEST FOR PROPOSAL, QUOTATION, OR INVITATION TO BID NOTICE.

1.0 Introduction

The National Aeronautics and Space Administration (NASA) is continually looking for opportunities to help advance the development of commercial space products and services. With the recent increase of U.S. private-sector companies interested in space exploration, and the associated potential for terrestrial spin-off applications, NASA is seeking to better understand U.S. industry's interests in a myriad of exploration activities. One such activity of particular interest is the development of high performance materials for spacecraft Thermal Protection Systems (TPS). NASA's Space Technology Mission Directorate is seeking input through this Request for Information (RFI) on industry-developed TPS material or system technologies that could support future NASA space missions while also having the potential to support commercial space and possibly terrestrial applications.

NASA has long recognized that the Entry, Descent, and Landing (EDL) phase of a mission represents a significant challenge for future planetary exploration missions. NASA is currently focused on developing efficient ways to reduce the spacecraft entry speed while simultaneously protecting the spacecraft from the resulting extreme aerothermodynamic heating. A current guiding focus of NASA's EDL investment is the development of the materials, components and architectures required to allow for more capable human and robotic missions that involve atmospheric entry. NASA recognizes that industry has a similar objective and is extremely interested in partnering with industry to aide in this pursuit.

There are a number of world-class arc jet test facilities located at NASA's Ames Research Center (ARC). These facilities are capable of exposing TPS materials and system components to a wide envelope of operating environments (heat fluxes, pressures, etc…) experienced during atmospheric entry. In fact, the arc jet testing of entry system materials and components has served as a critical and necessary performance and qualification testing standard prior to their utilization on an actual entry vehicle. NASA is interested in making these facilities available for the evaluation of novel TPS materials and system components under development by private organizations and other government agencies. Specifically, NASA is exploring the efficacy of making these test facilities available on a limited and competed basis in exchange for sharing of the resultant performance test data with NASA. TPS material and system component technologies demonstrating superior performance characteristics during testing and that have significant appeal for future NASA missions, would potentially gain consideration for further development, demonstration, or mission application opportunities.

As part of this partnership, NASA would provide:

- Arc jet testing time in one of several facilities (see Appendix B for additional information) and at conditions of interest to future entry system missions (see Appendix A for additional information).
- Detailed designs for acceptable and existing material system test samples, model instrumentation and model holders (see Appendix C for additional information).
- NASA personnel to assist in the further development and design of the TPS material or system component.
- Labor resources necessary to execute the final assembly of the instrumented test models and perform the technology performance evaluations.
- Resources required to operate the data acquisition system and to store the acquired data.
- Access to the facility during preparation for, and execution of, the test program.
- Protection of proprietary materials and data during test preparation and execution.
- Post-test analysis and expert evaluation of the acquired data.

NASA's external partner would provide:

- The expected performance characteristics of the TPS material or system component as they relate to potential applications of benefit to NASA's future missions or other missions in the overall U.S aerospace enterprise.
- TPS material / system test models for arc jet evaluation, as well as the necessary instrumentation and model holders or the resources to obtain them.
- Resources required for the partner to witness the technology evaluation including partner's labor and travel.

2.0 Industry - NASA Partnership

An industry-NASA partnership would:

- Capitalize on NASA's history of investments in space technologies and expertise.
- Leverage NASA arc jet facilities used as the benchmark standard to evaluate TPS material and system performance.
- Explore the possibility of maturing promising TPS material and system component technologies through a unique and mutually beneficial partnership.

3.0 Potential NASA Contributions to a Partnership

The potential NASA contributions to a partnership with U.S. industry include:

- **Technical Expertise**: NASA envisions that an integrated team comprised of NASA civil servants and an industry partner could work together to design, develop, analyze, and test TPS material and system components.
- **Test Facilities**: NASA will provide to partners, at no cost, access to world-class arc jet test facilities. The capabilities for the existing test facilities can be found at: http://www.nasa.gov/centers/ames/thermophysics-facilities/#.VMm-u0Y77CQ.

Note that no exchange of funds is envisioned between NASA and the partner(s). The type of agreement to be employed for this partnership is to be determined, but options include a Space Act Agreement, Cooperative Research and Development Agreement (CRADA), or other (ref. NASA Policy Directive (NPD) 1050.1l, *15 USC* §3710a(d)(1)). As part of this RFI, NASA is interested in obtaining information on other partnering agreements of interest to potential partners. The key perspective is that NASA would provide personnel, goods, services and facilities, but not direct funding.

4.0 Information Requested

The responses to this RFI should include the following information:

- **Company information:** Company name and address, point-of-contact name, e-mail address, and phone number.
- **Feasibility of a partnership**: Is a cooperation feasible? What type of arrangement and agreement with NASA is desired and why? Identify any particular considerations, circumstances, or issues that would need to be addressed in an agreement. For example, what are your expectations regarding the allocation of intellectual property rights? Finally, what is your timeframe of interest?
- **Technology concept:** Describe the proposed TPS material or system component technology or technologies and how they would meet NASA's EDL goals and/or the goals of other government agencies or the commercial space sector.
- **Potential NASA contributions:** If applicable, what expertise and support does your company need from NASA? What facility (or facilities) are you most interested in gaining access to as part of this partnership? What are the type(s), number, conditions, and durations of the tests desired?
- **Technology Readiness Level:** What is the Technology Readiness Level (TRL) of the technology described in the RFI response? Include sufficient information/data substantiating the documented TRL.
- **Business model:** Does your intended business strategy offer commercial services or is it to conduct exploration and prospecting for your own purposes? Have you identified potential customers or developed business plans around your envisioned activities? How firm is the demand for products or service stemming from this capability? What revenue model and pricing strategy have you established? How stable is your anticipated income stream?

5.0 Submitting Responses

Responses to this RFI (NNH15ZOA005L) must be submitted electronically using the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) at http://nspires.nasaprs.com. It is important to note that some of the functionality of the NSPIRES system uses terminology that does not exactly track to the collection of RFI data. For instance, when submitting responses to this RFI, submitters will be prompted to "Access 'Proposals/NOIs' in the NSPIRES Options Page." Use of the term "proposals" and "notice of intent" in these instructions does not mean that NASA is inviting proposals or offers in response to this RFI.

Responses are limited to no more than 15 pages and should be uploaded as a single PDF file attachment not to exceed 10MB at the NPIRES web site (http://nspires.nasaprs.com). The information provided in response to this RFI will not be disclosed publicly or used outside of the government for any purposes.

NSPIRES Account Registration

All respondents are required to register with NSPIRES and are urged to access this site well in advance of the RFI due date to familiarize themselves with its structure and enter the requested identified information. This data site is secure and all information entered is strictly for NASA use only. Respondents do not have to affiliate with an organization during registration to submit an RFI. Respondents will submit the RFI directly and do not have to have an authorized organizational representative submit on their behalf. To register for an account, go to: http://nspires.nasaprs.com/external/and click on "Getting an Account" on the left hand margin of the screen.

Creating Your RFI Response

Responses must be submitted using the "notice of Intent (NOI)" module within the NSPIRES system. To initiate an RFI response:

- Log in using your NSPIRES user name and password http://nspires.nasaprs.com/external/
- Access "Proposals/NOIs" in the NSPIRES Options Page.
- Click on the "Create NOI" button on the right side of the screen. Select the "NASA Request for Information Game Changing Development Program: Potential Industry/NASA Partnership in the Development and Assessment of High Performance Thermal Protection System Materials (NNH15ZOA005L)
- Follow the step-by-step instructions provided in NSPIRES to complete your RFI. Requests for assistance in accessing and/or using the NSPIRES website should be submitted by e-mail to nspires-help@nasaprs.com or by telephone to (202) 479-9376 Monday through Friday, 8:00 AM – 6:00 PM Eastern Time. FAQs on NSPIRES may be accessed through the Proposal Online Help site at http://nspires.nasaprs.com/external/help.do. Tutorials of NSPIRES are available at http://nspires.nasaprs.com/tutorials/index.html.

The information is requested for planning purposes only, subject to Federal Acquisition Regulation (FAR) Clause 52.215-3, entitled "Solicitation for Information for Planning Purposes." While the government may use the information obtained through this RFI to develop a subsequent solicitation seeking private/public partnerships, the release of this RFI does not guarantee that the government will issue a solicitation in this area nor does it obligate the government to invest any resources specific to the targeted technology area.

Appendix A: Planetary Entry Missions and Conditions

The following table provides data for the demanding entry environments associated with various solar system destinations. The responder is cautioned that specific mission design parameters could result in an entry environment that is different than those documented in the following table. Also, note that the entry environment parameters such as peak stagnation heat-flux and peak stagnation pressures does not represent upper or lower limit as large bodies with turbulent transition may experience heat-fluxes higher than the stagnation and, depending on the geometry, the lower heat-flux limit could result on the lee-side or back shell.

Planet	Mission Attributes	*Entry*	Entry Velocity, km/s	Peak Total Heating, W/cm2	Peak Stagnation Pressue, atm	Heat-load Stagnation, J/cm2	Aeroshell Size,m
Venus (Co2)	Probes, Landers, Balloons	*Ballistic*	~11.5	~5000	~8.0	~12000	3.5
	Orbiters and Probes	*Aerocapture*	~11.5	~1500	~1.5	~15000	2.65
		Entry from orbit	~ 4.0	~300	~0.3	~3000	2.65
Earth (Air)	Enceladus, Comets & Asetriods)	*Ballistic*	~ 11.0 - ~16.0	~1200 - ~3000	~0.3 - ~0.5	~6000 - ~20,000	~1
	Human Return from Asteroid	*Lifting*	~ 12.0	~1000	~0.5	~50,000	5
	Human Return from Mars	*Lifting*	~ 13.0	~3000	~0.5	~100,000	5
Mars (Co2)	Robotic (MSL Class)	*Lifting*	~7.0	~200	~0.3	~10,000	4.5
	Human and Cargo	*Aerocapture & Direct Lifting*	~7.0	~130 - ~450	~0.5	~15,000	~15 ~20
Jupiter (H2/He)	Probes	*Ballistic*	~48.0	30,000	10	300,000	~1.5
Saturn (H2/He)	Probes	*Ballistic*	~26.0	4500	3	~150,000	~1.0
Titan (CH4/N2)	Landers and Probes	*Ballistic*	~6.5	~120	0.3	~6000	~3.0
	Aerocapture	*Lifting*	~6.5	280	0.3	~35000	~3.5
Neptune (H2/He)	Probes	*Direct entry*	21.2				~1.5
	Orbiter and Probes	*Aerocapture*	~29	~3500		250,000	~3.5
Uranus (H2/He)	Probes	*Direct entry*	19.2	~1000 - ~2500	~2.0 - ~20.0	50,000	~1.0
	Orbiter and Probes	*Aerocapture and Entry from Orbit*		~800	~0.4	200,000	~3.5

Appendix B: Data for NASA's Nozzles, Test Article Sizes, and Possible Test Conditions for NASA's Arc Jet Facilities

NASA Ames Aerodynamic Heating Facility (AHF)

Stagnation point test of PICA thermal protection material in the AHF facility.

Mission: The Aerodynamic Heating Facility is designed to match heating rates of Earth or planetary hypersonic entry to enable the selection, validation and qualification of thermal protection systems (TPS) and materials.

Location: NASA Ames Research Center, Moffett Field, CA, United States.

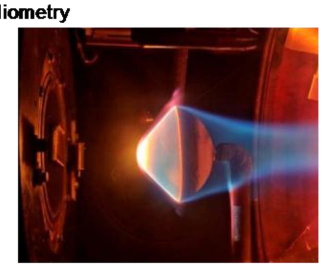
Type of tunnel: Huels and constricted arc heater facility.

Test gas	Air, N_2	Test duration (min)	≤ 30	
Nozzle exit (mm)	Conical (θ/2=8°), Ø 178, 305, 457, 610, 762, 914	Test article type	Stagnation point	Wedge
Input power (MW)	20	Test article size (mm)	< Ø 350	660X660
Bulk enthalpy (MJ/kg)	2-33	Surface pressure, kPa	0.5-45	0.1
Flow rates (kg/s)	0.05-0.7	Heating rate (kW/m^2)*	90 - 9000	0.6-250

*Cold wall fully catalytic surface on a 102-mm Ø sphere

Instrumentation:

- Hot wall temperature: thermocouples, IR pyrometry and radiometry
- Pressure: Pitot/static
- Cold wall heat flux: calorimetric probes of Gardon and slug types and null-point calorimetry
- Optical diagnostics: optical emission spectroscopy (OES), laser induced fluorescence (LIF)

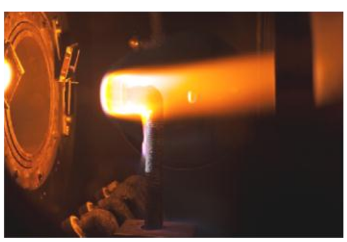


Full scale SPRITE capsule geometry at simulated entry conditions

References:

Grinstead, J.H., Harris, C.L., Yeung, D., Scott, G.P., Porter, B.J., Graube, P., and Greenberg, R.B., "Next-generation Laser-induced Fluorescence Diagnostic Systems for NASA Arc Jet Facilities," *In 47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition*, AIAA 2009-1521, January 2009, Orlando, FL.

Terrazas-Salinas, I., et. al., "Test Planning Guide for NASA Ames Research Center Arc Jet Complex and Range Complex," Document A029-9701-XM3 Rev.C., April 2009.



AHF stagnation point test samples, calorimetric and pitot probes.

Information Contacts:
Ernest Fretter,
+1 (650) 604-6166,
ernest.f.fretter@nasa.gov
http://thermo-physics.arc.nasa.gov/

NASA Ames Interaction Heating Facility (IHF)

The segmented arc heater in the IHF.

Mission: The Interaction Heating Facility is designed to study aerodynamic heating in the thermal environment arising from the interaction of an energetic flow field during a hypersonic entry into a planetary atmosphere.

Location: NASA Ames Research Center, Moffett Field, CA, United States.

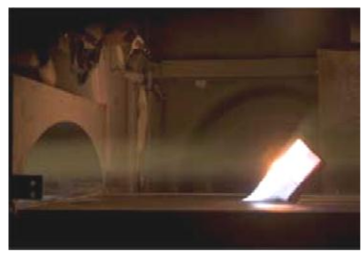
Type of tunnel: Constricted arc heater facility.

Test gas	Air		**Test duration (min)**	≤ 60	
Nozzle exit (mm)	Conical (θ/2=10°), Ø 152,330,533,762 &1041	Semielliptical, 203x813	**Test article type**	Stagnation point	Wedge/Flat plate
Input power (MW)	60		**Test article size (mm)**	Ø 380	610x610
Bulk enthalpy (MJ/kg)	2 to 28		**Surface pressure, kPa**	1-155	0.01-2
Flow rates (kg/s)	0.03 to 1.7		**Heating rate (kW/m^2) ***	250-20000	60-4000

****Cold wall fully catalytic to a 102mm ø sphere (stagnation)***

Instrumentation:

- Hot wall temperature: thermocouples, IR pyrometry and radiometry
- Pressure: Pitot/static
- Cold wall heat flux: calorimetric probes with copper gauges (Gardon, Slug and Null Point types)
- Optical diagnostics: optical emission spectroscopy (OES), laser induced fluorescence (LIF), photogrammetric ablation rate



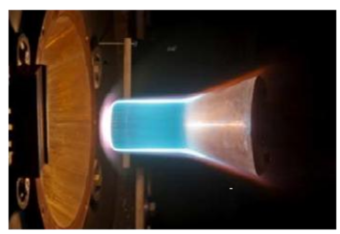
Large scale panel/pylon test in IHF.

References:

Winter, M.W., Raiche, G.A., Terrazas-Salinas, I., Frank, C.L.H., White, B., and Taunk, J.S., "Measurements of Radiation Heat Flux to a Probe Surface in the NASA Ames IHF Arc Jet Facility," *In 43rd AIAA Thermophysics Conference*, AIAA 2012-3189, June 2012, New Orleans, LA.

Terrazas-Salinas, I., et. al., "Test Planning Guide for NASA Ames Research Center Arc Jet Complex and Range Complex," Document A029-9701-XM3 Rev.C., April 2009

Stewart, D.A., Gökçen, T., and Chen, Y.-K., "Characterization of Hypersonic Flows in the AHF and IHF NASA Ames Arc-Jet Facilities," *In 41st AIAA Thermophysics Conference*, AIAA 2009-4237, June 2009, San Antonio, TX.



UHTC ceramic tests in IHF

Information Contacts:

Ernest Fretter +1 (650) 604-6166
ernest.f.fretter@nasa.gov,
http://thermo-physics.arc.nasa.gov/

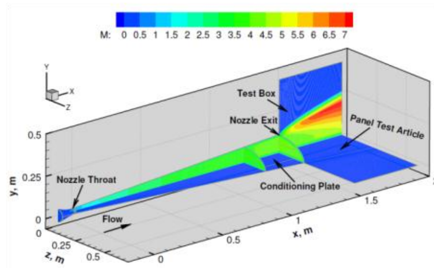
NASA Ames Panel Test Facility (PTF)

Mission: The Panel Test Facility is designed to enable testing spacecraft heat shield material samples in a high enthalpy, moderate shear boundary layer flow field. A modified version is available for higher shear and pressure conditio ns (TPTF).

Location: NASA Ames Research Center, Moffett Field CA 94035-1000, USA.

Type of tunnel: Constricted arc heater facility.

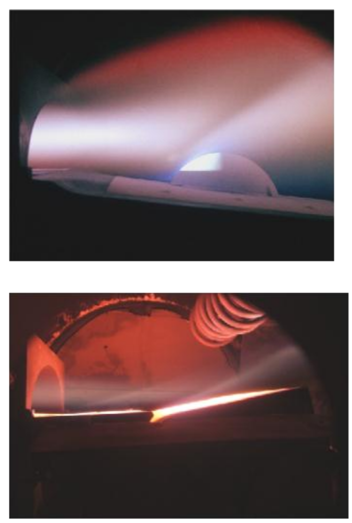
Test gas	Air
Nozzle type	Semielliptical
Nozzle exit (mm)	102x432 (TPTF: 38x170)
Input power (MW)	20
Bulk enthalpy (MJ/kg)	4.6 - 32
Shear Stress (Pa)- est.	5-30 (TPTF: 80-270)
Test duration (min)	▯ 30
Test article type	Flat plate, -5 to +8°
Test article size (mm)	406x406 (TPTF: 103 x 103)
Surface pressure, kPa	0.05-5 (TPTF: 1 – 30)
Heating rate (kW/m2)	20-500 (TPTF: 80 – 2000)



Computed PTF nozzle flow and flowfield over the calibration plate at 0▯ deflection.


Side view of a PTF run

Instrumentation:
- **Hot wall temperature: thermocouples, IR thermograp hy, radiometry**
- **Pressure: Pitot/static**
- **Cold wall heat flux: copper gauges**
- **Optical emission spectroscopy (OES)**


MER TIRS cover test (top)
Body flap test in PTF (bottom)

References:

Gökçen, T., Alunni, I.A., and Skokova, K.A., "Computational Simulations of Panel Test Facility Flow: Compression-Pad Arc-Jet Tests," *In 42nd AIAA Thermophysics Conference*, AIAA 2011-3635, June 2011, Honolulu, HI.

Balboni, J.A., Gökçen, T., Frank, C.L.H., Taunk, J.S., Noyes, E. and Schickele, D., "Calibration of the Truncated Panel Test Arc-Jet Facility," *In 41st AIAA Thermophysics Conference*, AIAA 2009-4090, June 2009, San Antonio, TX

Terrazas-Salinas, I., et. al., "Test Planning Guide for NASA Ames Research Center Arc Jet Complex and Range Complex," Document A029-9701-XM3 Rev.C., April 2009

Information Contacts:
Ernest Fretter, **+1 (650) 604-6166**
ernest.f.fretter@nasa.gov
http://thermo-physics.arc.nasa.gov/

NASA Turbulent Flow Duct (TFD)

Mission: The Turbulent Flow Duct is designed to produce high enthalpy supersonic turbulent flow over the surface of a wall-mounted panel in the constant-area section of a duct.

View of the TFD test section

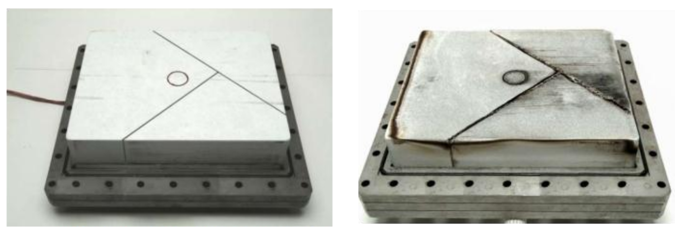
Location: NASA Ames Research Center, Moffett Field CA 94035-1000, USA

Type of tunnel: Huels (Linde) arc heater facility.

Test gas	Air, N_2	**Test duration (min)**	□ 30
Nozzle exit (mm)	51x229	**Test article type**	Flat plate
Input power (MW)	12	**Test article size (mm)**	203x254 or 203x508
Bulk enthalpy (MJ/kg)	3 - 9.5	**Surface pressure (kPa)**	2-15.2
Shear Stress (Pa) - estimate	50 - 720	**Heating rate (kW/m^2)**	23-681

Instrumentation:

- □ Hot wall temperature: thermocouples, IR thermography and radiometry
- □ Pressure: static
- □ Cold wall heat flux: Gardon gauges



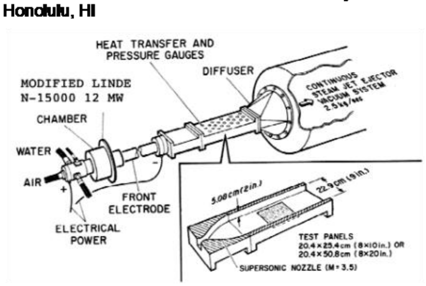
Turbulent flow duct test model prior to (left) and after testing (right).

References:

Terrazas-Salinas, I., et. al., "Test Planning Guide for NASA Ames Research Center Arc Jet Complex and Range Complex," Document A029-9701-XM3 Rev.C., April 2009.

Covington, M.A.; and Vojvodich, N.S.: "Turbulent Flow Studies in Two Arc-Heated Duct Facilities." J. Spacecraft and Rockets, vol. 9, no. 6, June 1972, pp. 441-447.

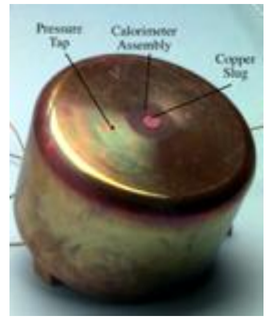
Alunni, A.L.; Olson, M.W.; Gökçen, T.; and Skokova, K.A.:"Comparisons of Surface Roughness in Laminar and Turbulent Environments for Orion Thermal Protection System." In 42nd *AIAA Thermophysics Conference*, AIAA 2011-3776, June 2011, Honolulu, HI



Information Contacts:
Ernest Fretter
+1 (650) 604-6166
ernest.f.fretter@nasa.gov
http://thermo-physics.arc.nasa.gov

Appendix C: Arc Jet Test Article Sample Holders

The test article design requires careful consideration to effecitvely achieve the test objectives within the constraints of the facility test conditions. NASA has designed and fabricated test samples that range from simple stagation models to more complex wedges and other shapes that can emulate flight geometries.



(a) Hemisphere (b) Iso-q (c) Flat face

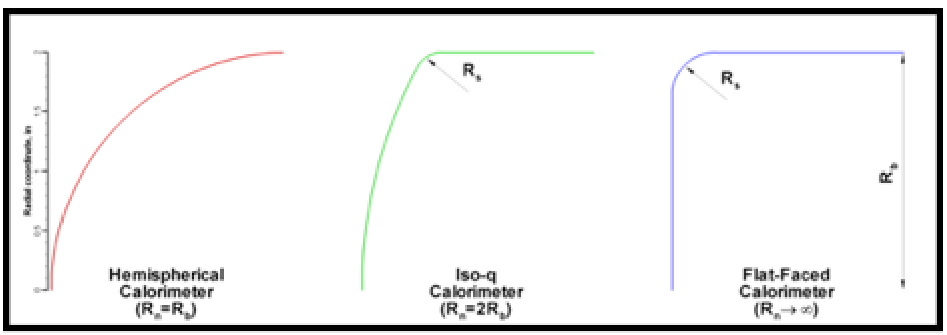


Figure 1. Standard stagnation calorimeters and their profiles are shown in the above pictures. Stagnation test articles are typically either flat face or iso-q shaped corresponding to the calorimeters shown above.

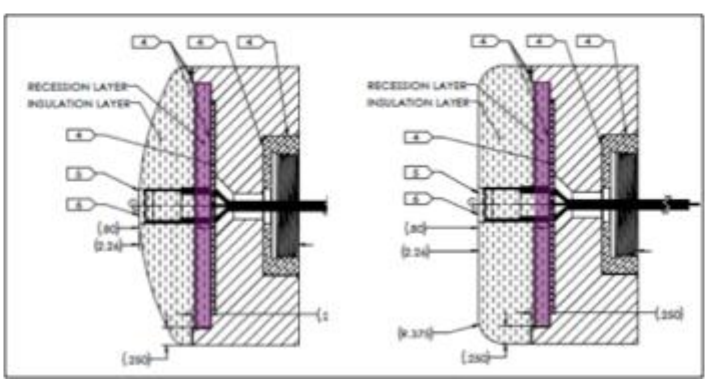
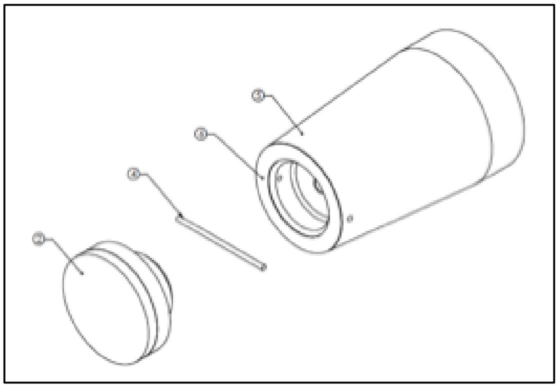


Figure 2. Iso-q and flat face models instrumented with thermocouple plugs are shown above.



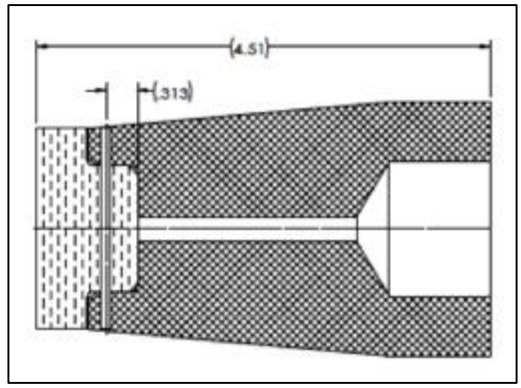


Figure 3. A simple flat face model may require a mechanical attachment (pin) in addition to bonding it to the model holder assembly to ensure the model does not disengage from the post after test cool down.

Figure 4. A wedge model can be designed to achieve a combination of heat-flux, pressure and shear within the limitation of the facility and the nozzles. Wedge models are more complex and pre-test computational predictions are required to ensure pre-existing water cooled wedges could be used in the exiting nozzle at appropriate arc jet operating conditions. The use of wedges will require close interaction between arc jet facility experts, model test designer, and the principal investigator.

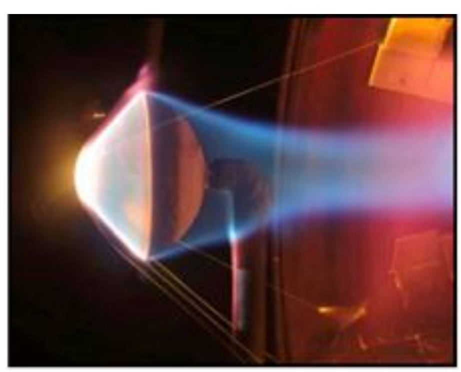


Figure 5. Larger test articles and complex shapes can provide both stagnation and gradients of heat flux, pressure, and shear for evaluation in a single run. These types of tests will require close collaboration between the model and test design experts to design the test article. The test planning as well as model design, manufacturing, and integration with instruments will require considerable schedule and is a more complex effort compared to simpler stagnation coupon tests

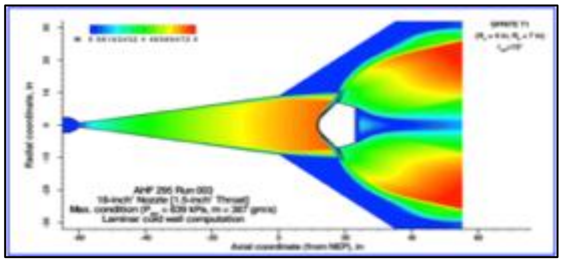


Figure 6. The instrumented pre-test model shown on the left consists of different materials and different integration (seams) that allows a single test to provide a wide range of data. The successful post-test article is shown on the right. The state of the art of simulation of the arc jet nozzle, test chamber including the test article via computational fluid dynamic simulation (CFD) is in a mature state allowing complex testing to be executed successfully.