

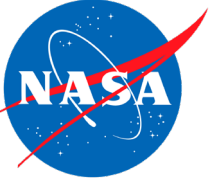
# **Alternate High-Enthalpy Test Facilities and Final Thoughts**

Stan Bouslog/NASA-JSC

With Inputs from

NASA-GRC/ARC/LaRC/MSFC, UT-Austin, U. of Vermont, U. of Illinois U-C

May 1, 2024



# GRC Variable Plasma Environmental Test Rig (VaPER)

## Test Facility Description

- 100kW Thermal Spray Torch
- Low pressure (variable chamber range: 0.75 – 40 mbar)
- Velocity of ~Mach 2
- Continuous Ar/He plasma
- X-Y torch movement for programmable motion control during exposure
- Test gases – air, N<sub>2</sub>, N<sub>2</sub>/O<sub>2</sub> mixtures, CO/Ar or CO/N<sub>2</sub> mixtures
- POC: Dr. Bryan Harder- bryan.harder@nasa.gov

## Test Conditions

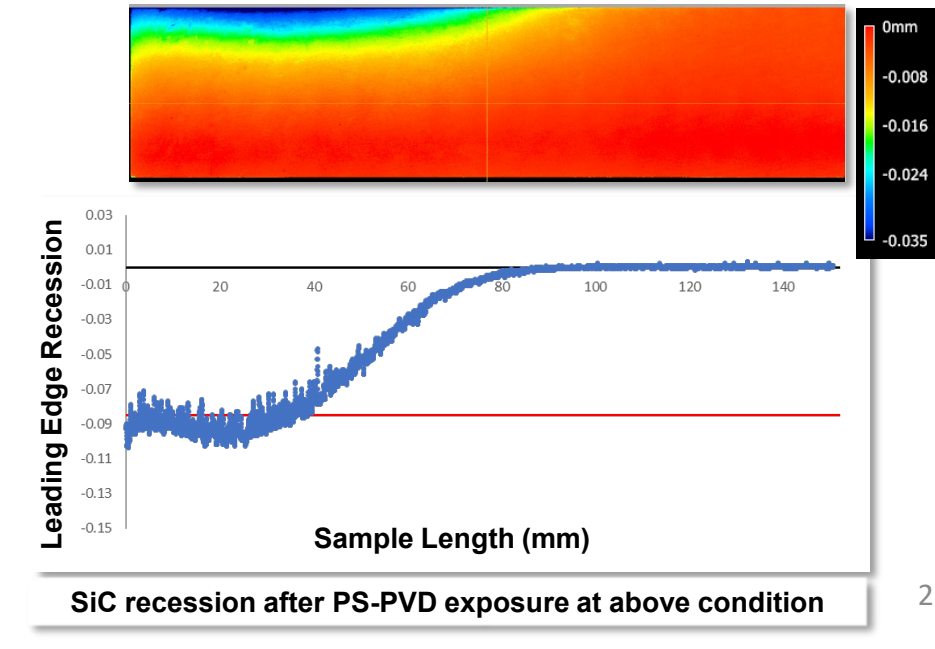
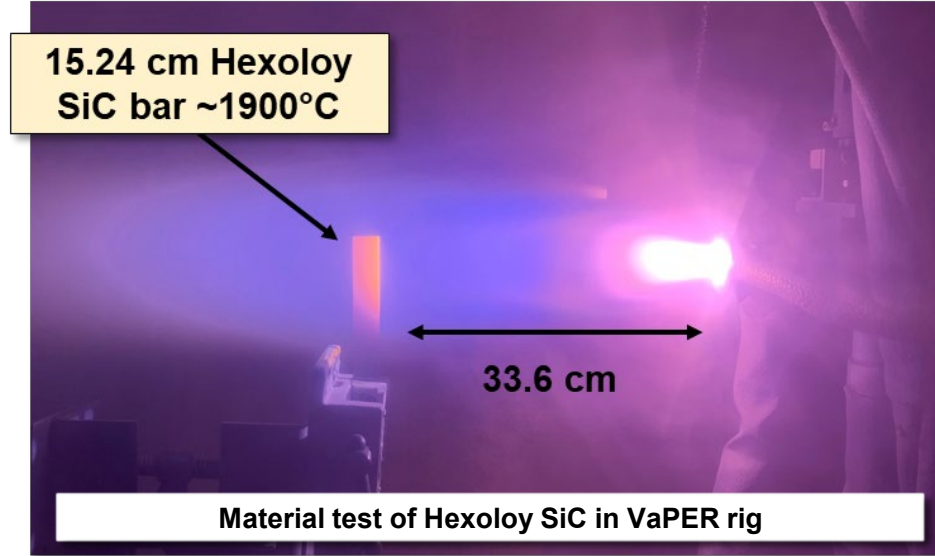
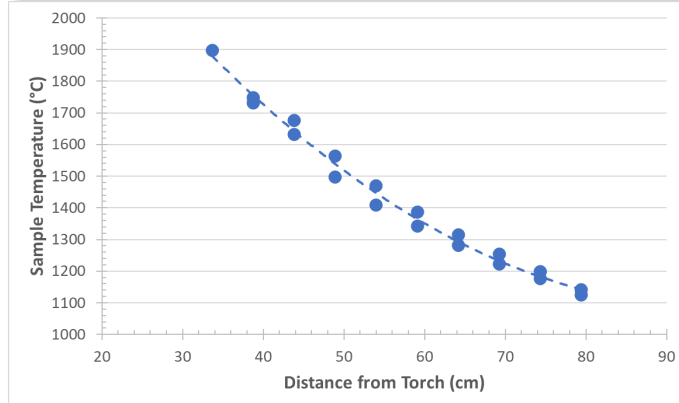
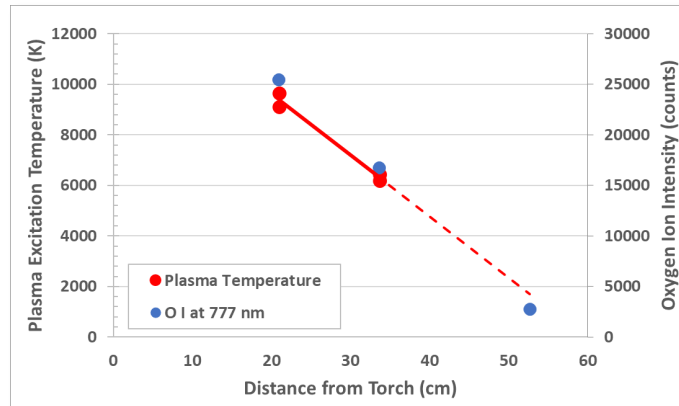
- Wide pressure and energy range
- Plasma excitation temperature: ~10,000K
- Heat flux: TBD, expected >200 W/cm<sup>2</sup>
- Plasma diameter: variable, 25-75mm
- Chamber: 1.5m with capability for water/instrumentation connections
- Test time range: minutes to hours (if needed)

## Instrumentation

- Optical Spectrometer to determine excitation levels of Ar, He, O, N, etc.
- Pyrometers and thermocouples
- Thermal imaging camera

## Future Plans

- Integrate pitot tube and slug calorimeter to determine heat flux
- Perform additional testing on baseline compositions





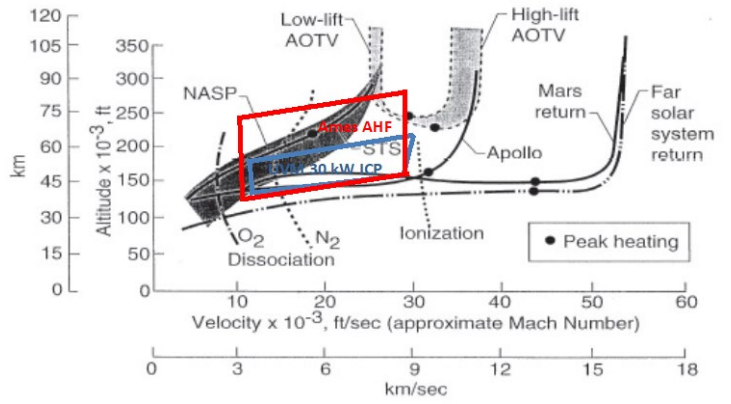
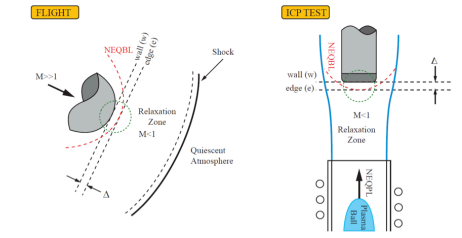
# University of Vermont 30 kW ICP Torch

## Test Facility Description

- 30kW Inductively Coupled Plasma (ICP) Torch
- Exhausts into vacuum chamber (100 – 760 Torr)
- Test gases – air, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, Ar and admixtures
- POC: Prof. Douglas Fletcher - dfletche@uvm.edu
- References: Owens et al, 'Development of a 30 kW Inductively Coupled Torch Facility for Aerospace Material Testing', AIAA-2010-4322; Fletcher and Meyers, "Surface Catalyzed Reaction Efficiencies in Oxygen Plasmas from LIF Measurements", *JTHT* 31 (2) pp 410-420

## Test Conditions

- Velocity- altitude
- Sub, supersonic nozzles



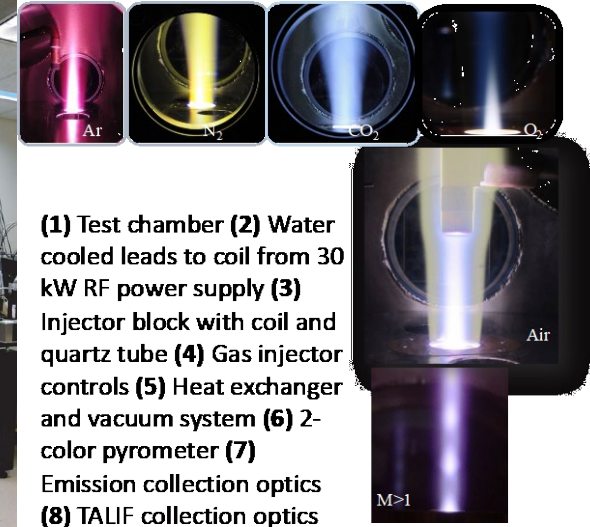
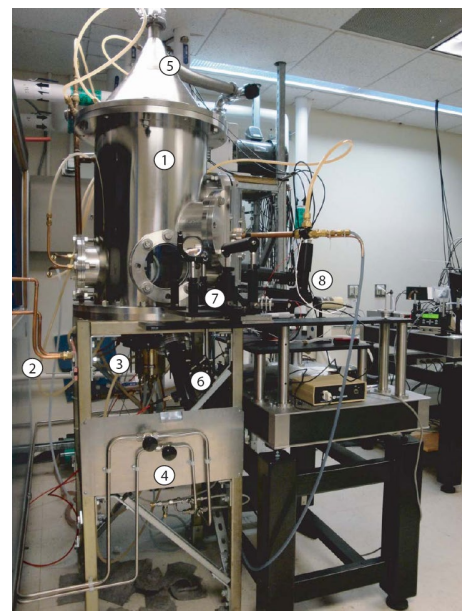
## Instrumentation

- Gardon and copper-slug heat flux gauges
- Pyrometers, IR camera
- Thermocouple measurements
- Emission spectrometers
- High-speed camera
- Flow field laser diagnostics

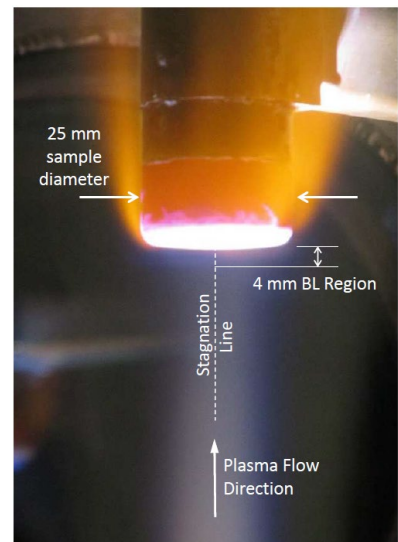
## Future Plans

- Continue measurements of reactants and products to characterize gas-surface interactions

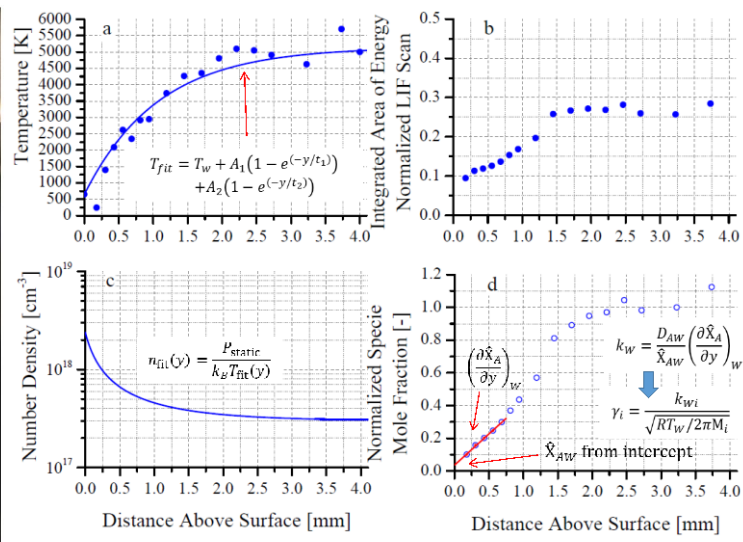
## Facility Layout (LIF Instrumentation not shown)



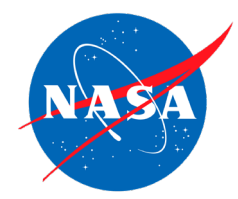
- (1) Test chamber (2) Water cooled leads to coil from 30 kW RF power supply (3) Injector block with coil and quartz tube (4) Gas injector controls (5) Heat exchanger and vacuum system (6) 2-color pyrometer (7) Emission collection optics (8) TALIF collection optics
- Flow reactor optical table at rear right.



Graphite in N<sub>2</sub> Plasma



LIF Measurements



# Hyperthermal Facility at MSFC 1.5 MW Arc Heater

## Test Facility Description

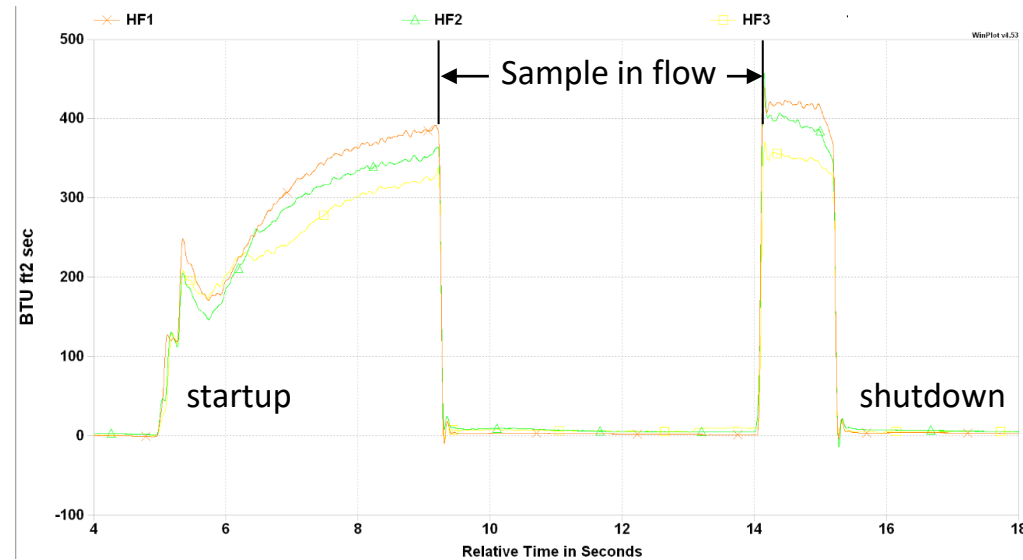
- 750 kW Continuous and 1.5MW Maximum Aerotherm Arc Heater
- Test Sections: Subsonic sandia channel, sonic 2D Nozzle, Vacuum Cabin (0.5 PSIA)
- Test gases: N<sub>2</sub>, O<sub>2</sub>, Air (Simulated), He, and H<sub>2</sub>
- POC: Melissa Costa – melissa.r.costa@nasa.gov
- Reference: Litchford et al, 'Magnetohydrodynamic Augmented Propulsion Experiment', AIAA-2002-2184

## Test Conditions

- Enthalpy: 400 – 20,000 Btu/lb
- Heat flux: 25 – 380 Btu/ft<sup>2</sup>-s
- Test article size:
  - Rectangular 0.84x0.84x4in
  - Stagnation
  - 4x4ft Vacuum Cabin w/ 4 sample stings
- Pressure: 0.04 atm to 15 atm

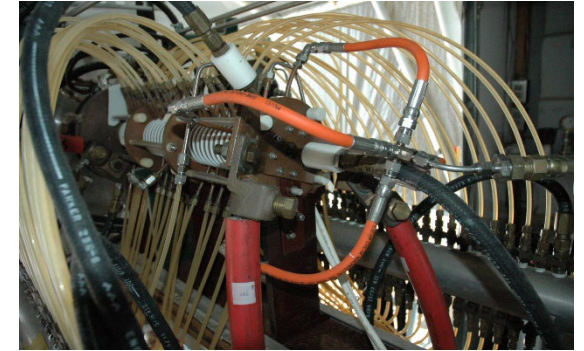
## Instrumentation

- Enthalpy: energy balance, mass balance and heat flux
- Temperature: thermocouple, thermopile, IR
- Recording: Pacific series 6000 DAQ, 100 channels, 10,000 samples/sec recording rate (Max)
- Video: Standard color video and High-speed color video



Sandia Channel Flow and Calorimeter Calibration

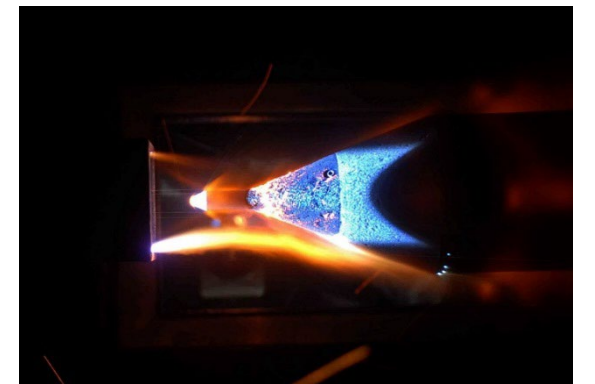
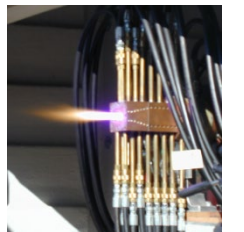
Test Setup



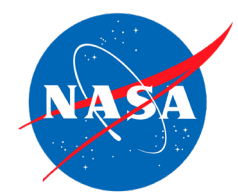
Vacuum Cabin



2D Nozzle



Pitot Tube During Test



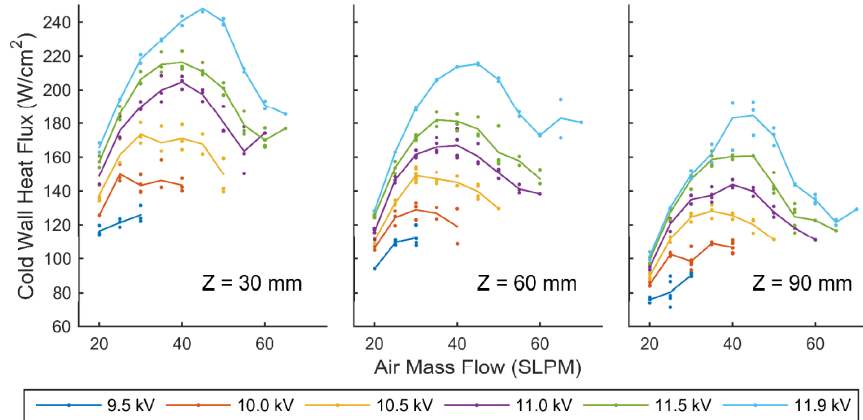
# The University of Texas at Austin 50 kW ICP Torch

## Test Facility Description

- 50kW Inductively Coupled Plasma (ICP) Torch
- Currently exhausts into ambient air; low-pressure coming soon
- Test gases – air, N<sub>2</sub>, N<sub>2</sub>/O<sub>2</sub> mixtures, CO/Ar or CO/N<sub>2</sub> mixtures
- POC: Dr. Noel Clemens - clemens@mail.utexas.edu
- Reference: Green et al, 'Characterization of a 50kW Inductively Coupled Plasma Torch for Testing of Ablative Thermal Protection Materials', AIAA-2017-0394

## Test Conditions

- Bulk Air Enthalpy range: 15 – 40 MJ/kg
- Heat flux: 90 – 225 W/cm<sup>2</sup>
- Test Article size – 30 mm

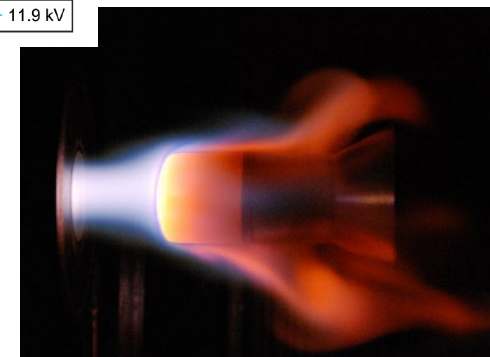


## Instrumentation

- Gardon and copper-slug heat flux gauges
- Pyrometers
- Thermocouple measurements
- Flow-field diagnostics including emission spectroscopy, laser-induced fluorescence and Coherent anti-Stokes Raman spectroscopy (CARS) to obtain profiles of temperature and concentrations of O, CO, CN and NO

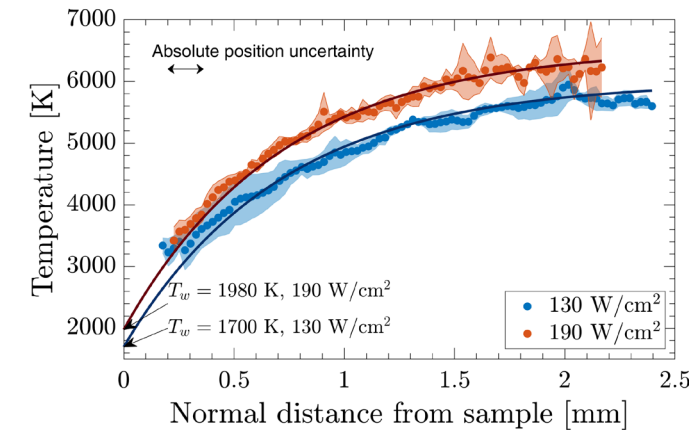
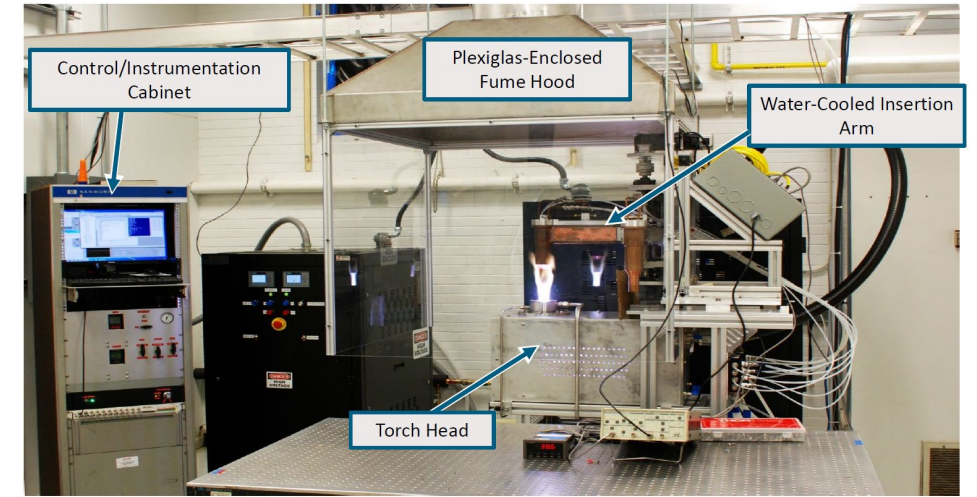
## Future Plans

- Attach torch to vacuum chamber to enable variable-pressure and supersonic conditions to be obtained

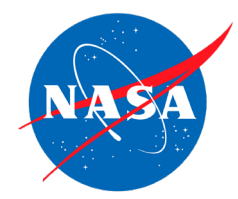


30 mm Dia. Model in Flow

## Test Setup



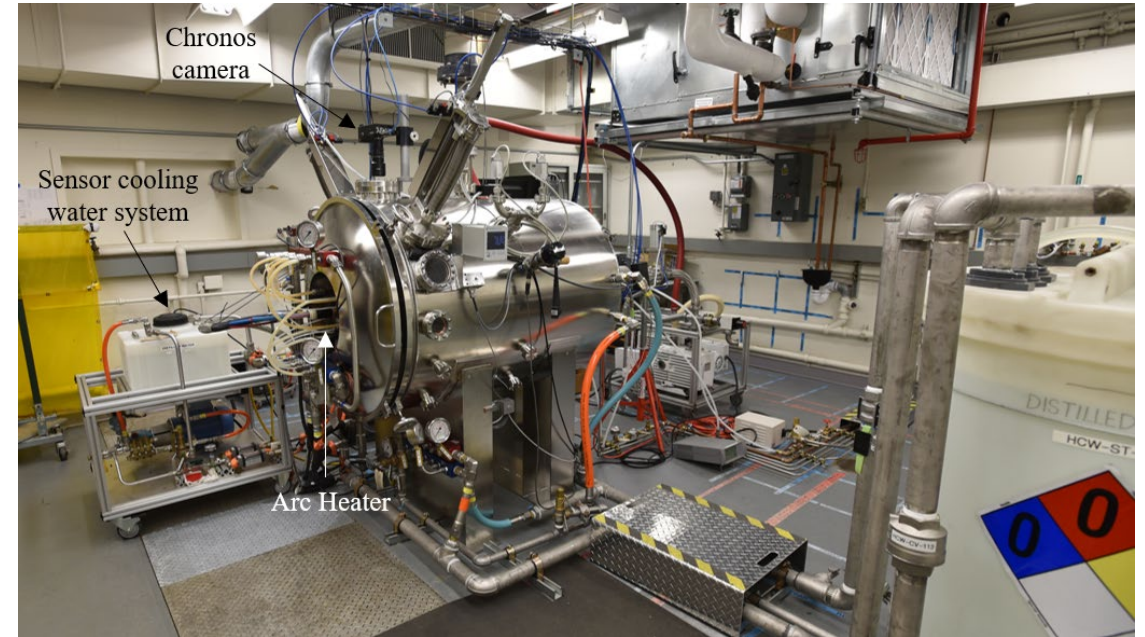
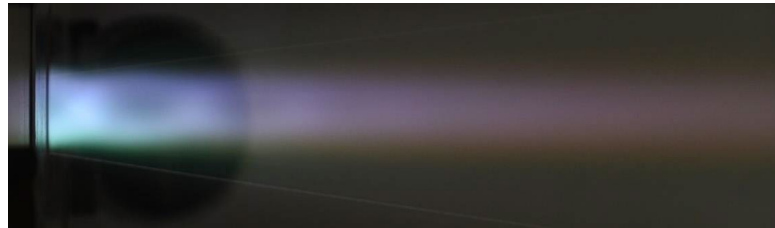
CARS Temperature profiles on stagnation line of graphite samples at two heat fluxes



# NASA Ames miniature Arc jet Research Chamber (mARC II)

## Test Facility Description

- 30 kW segmented constricted arc heater
- Test gases: air (potential to run CO<sub>2</sub>/N<sub>2</sub> with minor upgrades)
- POC: Dr. Megan MacDonald (megan.e.macdonald@nasa.gov)
- References
  - MacDonald et al., Characterizing Heat Flux in the miniature Arc jet Research Chamber (mARC II), AIAA 2023-3298
  - Luis et al., Emission spectroscopy characterization of electrode species in the freestream flow at the NASA Ames miniature Arc Jet II facility, JQSRT 272 (2021) 107752



## Test Conditions

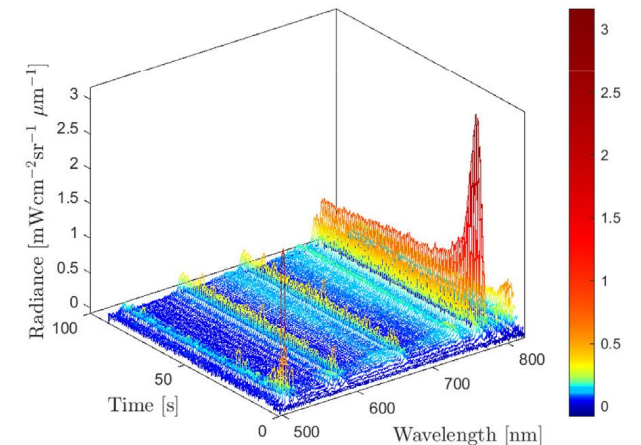
- Bulk air enthalpy range: 4 – 12 MJ/kg
- Heat flux: 200 – 1900 W/cm<sup>2</sup>
- Test article diameter – 12.5 mm

## Instrumentation

- Facility data (pressure, temperature, current, voltage, mass flow)
- Trident sweep arm that accommodates
  - Gardon gauges and coaxial thermocouple
  - Pitot probe
- Emission spectroscopy, Langmuir probes

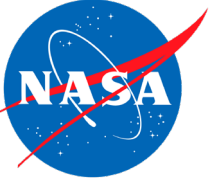


Trident sweep arm with water-cooled sensors



(a) Entire test time

Jet emission spectra during startup



# Hypersonic Material Environmental Test System (HyMETS) Facility

NASA Langley Research Center

## Test Facility Description

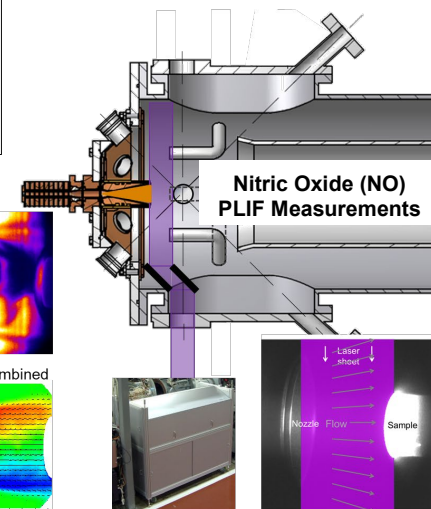
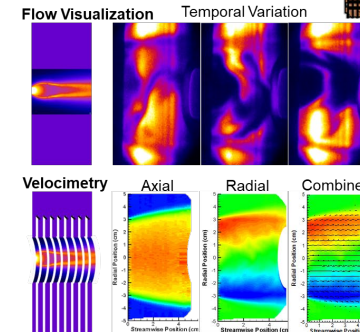
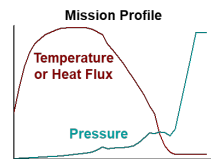
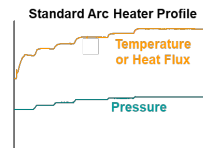
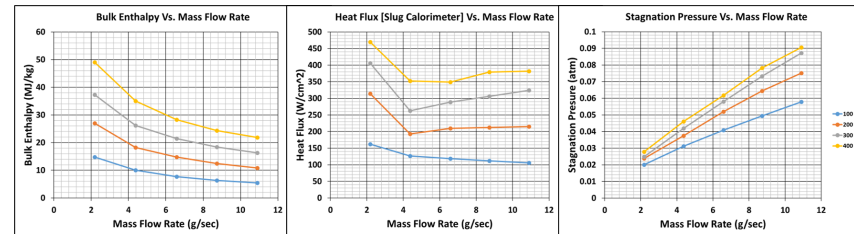
- 400 kW segmented arc-jet
- Discretized gas injection (N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, Ar, He, etc.)
- Fast and relatively inexpensive screening facility
- POC: Scott Splinter - scott.c.splinter@nasa.gov
- Reference: S. C. Splinter et al, "Comparative Measurements of Earth and Martian Entry Environments in the NASA Langley HYMETS Facility", AIAA-2011-1014

## Test Conditions

- Bulk Enthalpy: 5.3 – 48.8 MJ/kg
- Heat flux: 100 – 470 W/cm<sup>2</sup>
- Stagnation Test Article size
  - 3.3 cm max diameter
  - 2.15 cm max thickness

## Instrumentation

- SiC conversion coated graphite pressure probe
- Medtherm cold-wall copper slug calorimeter
- 2-color Modline 5R-3015 pyrometer (1000 – 3000°C)
- Back face thermocouple measurements (1-3 channels)
- Infrared MWIR camera
- High-speed HD camera
- Mobile laser system
- UV, UV-Vis, and NIR spectrometers
- Narrow view radiometer rated to 114 W/cm<sup>2</sup>
- NO/O-atom LIF measurements

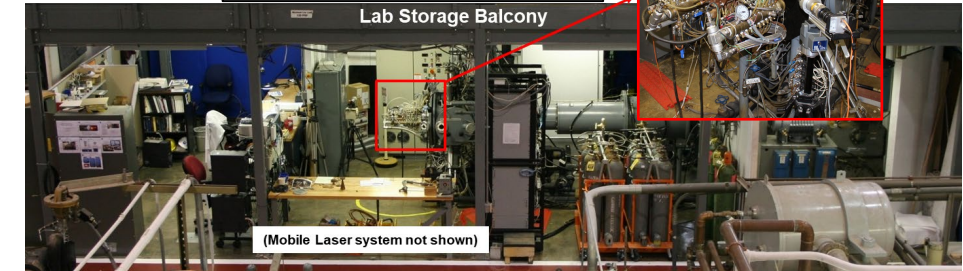


## Future Plans

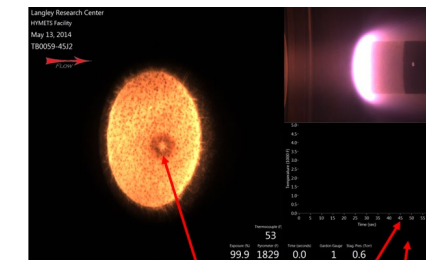
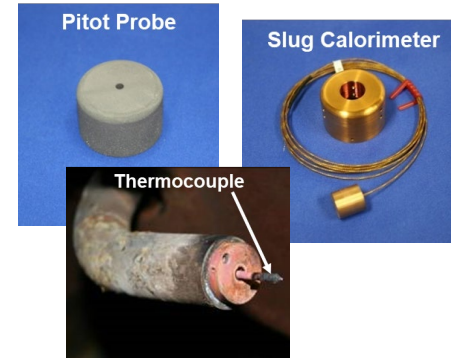
- Permanent infrastructure for spectrometers, laser, and HD camera
- Characterization of facility with Mach 3 nozzle
- Test envelope extension with a Mach 7 nozzle with varying diffusers

## Baseline Configuration

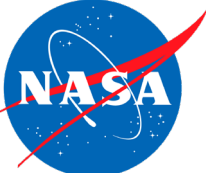
- 4 Arc Segment Packs
- Mach 5 Nozzle
- 6-inch Collector/Diffuser
- Have Mach 3 nozzle and other diffusers



Specimen Preparation, Test Monitoring, and Facility Control Section | Main Test Chamber and Power Supply Section | Diffuser / Heat Exchanger, Instrumentation Rack, and Gas Cylinder Section | Vacuum Pump Section



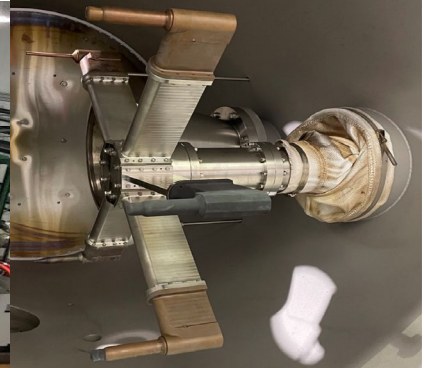
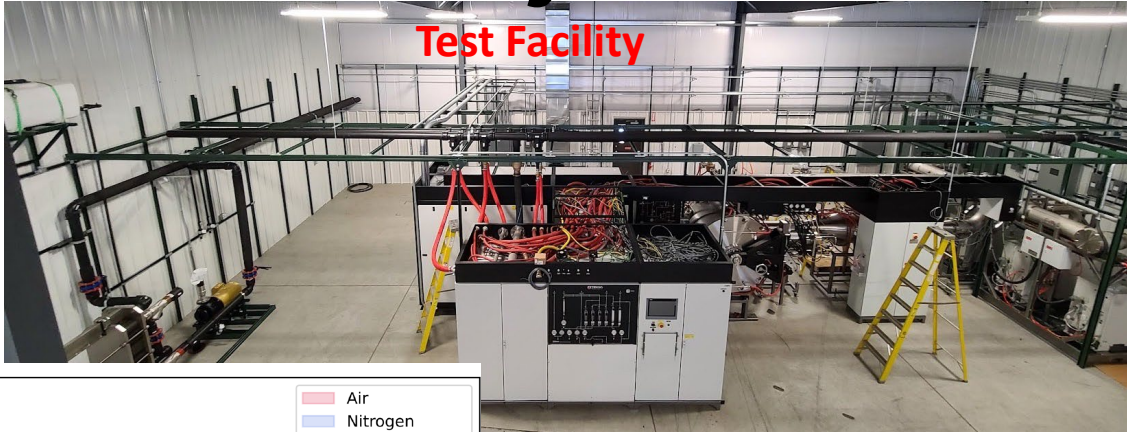
Pyrometer "Aiming" Spot | Real Time Data Overlays | Current Sting Name Displayed Here



# Plasmatron X: University of Illinois U-C

## Test Facility Description

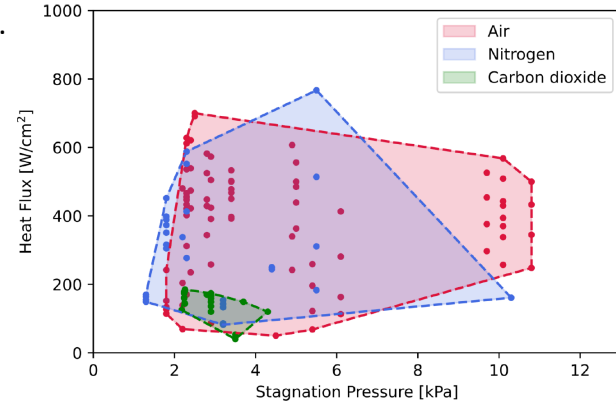
- 350kW Inductively Coupled Plasma (ICP) Torch
- Vacuum Test chamber with 5 view ports
- Test gases – Ar, Air, O2, N2, CO2, H2, CH4, He
- POC: Dr. Francesco Panerai - fpanerai@illinois.edu
- Reference: Aerothermal characterization of the Plasmatron X Wind Tunnel: Heat flux, Stagnation Pressure and Jet Unsteadiness, AIAA SCITECH 2023, Jan. 2023. AIAA 2023-1338



Probe Model Holder

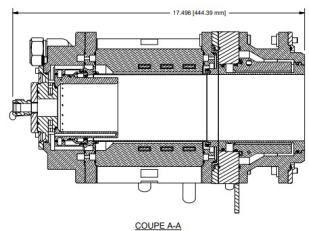
## Test Conditions

- Bulk Air Enthalpy range – 2 – 36 MJ/kg
- Flow Rates - 5–70 g/s
- Mach number – 0.5 – 4.2
- Heat flux – 50 – 700 W/cm<sup>2</sup>
- Stag. Pressure – 0.02 to 0.1 atms
- Test Model - < 60 mm Diameter

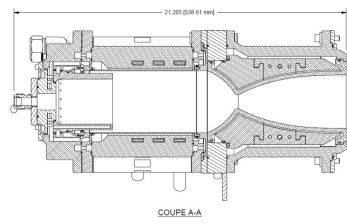
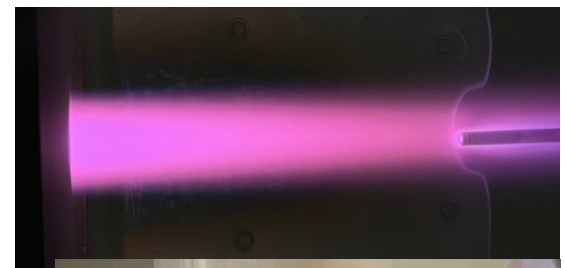


## Test Envelope

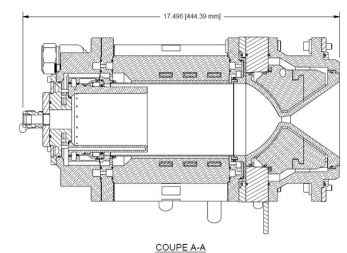
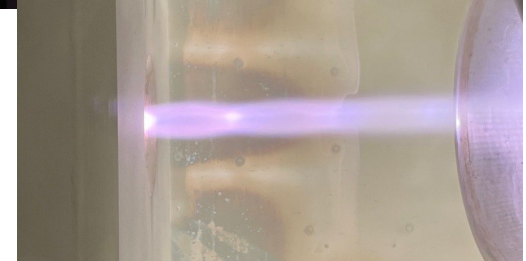
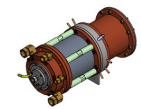
## Three Nozzles



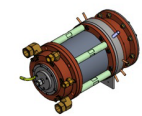
100 mm D



86.5 mm D

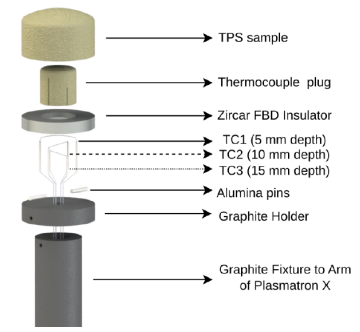
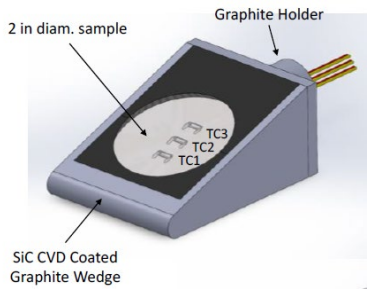


96.5 mm D

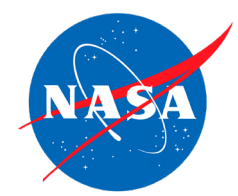


## Instrumentation

- Gardon heat flux gauges
- Thermocouple measurements
- Pyrometers & IR camera
- High-speed/resolution imaging
- Optical Emission spectroscopy
- Flow field laser diagnostics



## Test Articles



# Final Thoughts

- Testing in Alternate Facilities
  - Many can provide relevant environments – high enthalpy air
    - Great for material screening
    - Often can vary conditions during tests and conduct long duration testing
    - Limited range of pressure and shear
    - Size limitations
  - ICP/Plasmatron provide cleaner flow – no copper contamination
    - Good for catalycity data
    - Material oxidation rates
    - Coating development
- When do you need the Big Arc-jets?
  - Full range of test conditions needed
    - Range of pressure and shear expected in flight
  - Size of test articles
    - Thermal model validation
    - TPS design features
      - Penetrations
      - Seams between tiles/blocks