Current Capabilities of the NASA Langley Arc-Heated Scramjet Test Facility

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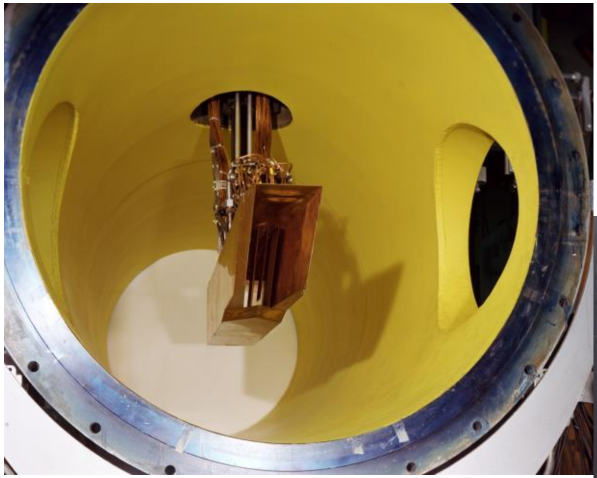
NASA Langley Research Center

OUTLINE

- Introduction
- Facility Description
  - Flight simulation capability
  - Overview
  - Low Mach Plenum & Nozzles
  - Tunnel operations
  - Test section and supported diagnostics
  - Support Systems
    - Air
    - Fuel
    - Vacuum
    - Data Acquisition System (DAS)
- Summary & Future Plans

For more than four decades, the AHSTF has served as a valuable resource to the U.S. hypersonic communities as an experimental platform for subscale scramjet engine performance and operability verification.



Mach 7 Subscale Airframe Integrated Scramjet Tests (1976-1988)

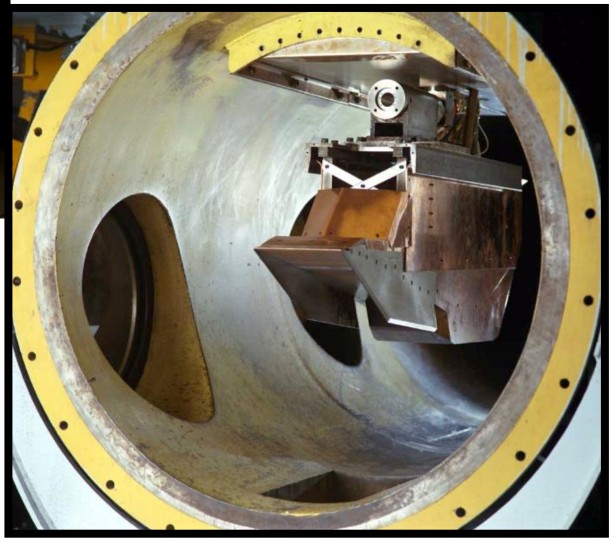
Facility characteristics:

- Mach 7 test conditions
- Mach 6 MOC 2-D nozzle
- Hydrogen fuel
- Silane ignition
- Short run durations (30 sec. typical)
- Fixed test conditions

NASP (1988-1995)

- Expanded envelope with Mach 4.7 and 6 square MOC contoured nozzles
- Improved test cell/cabin access, portings, and model sting

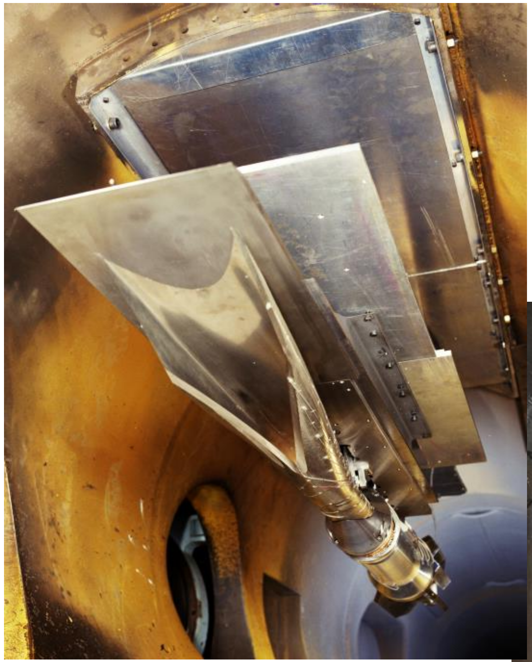
Hyper-X (1995-2000)



Introduction, cont'd

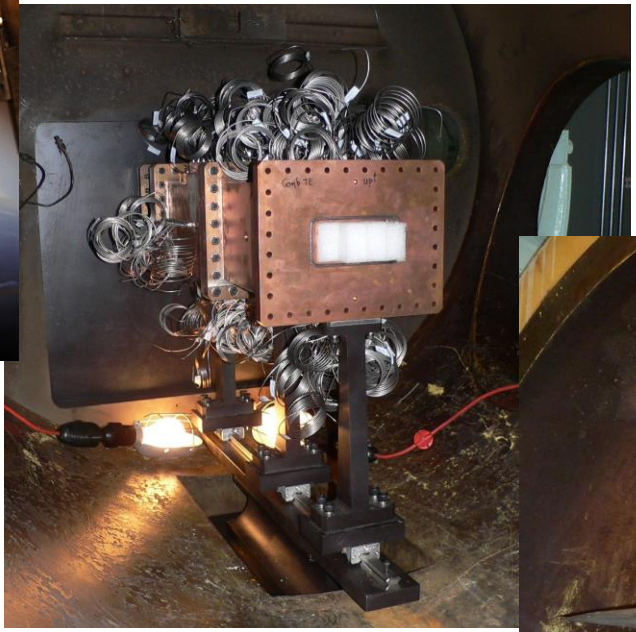
More recent modifications now include …

- *Dynamic test condition variability*
- *Dynamic Sample Rake Traverse/Nozzle calibration system*
- *Flight simulation range extended down to Mach 2.0*
- *New nozzles – M2.2 & M3.5*



REST SJ Model (2006-2008)

- New Mach 6–2D nozzle
- Automated facility controls
- Upgraded power supply



HiFIRE Direct-Connect Rig (2009-2012)

- First direct connect test
- Hydrocarbon fuels (gaseous)
- Spark ignition
- Real-time enthalpy sweeps

Enhanced Injection and Mixing Test (2015 -)

- Demonstrated extended run duration
- Gas sampling and non-intrusive diagnostics

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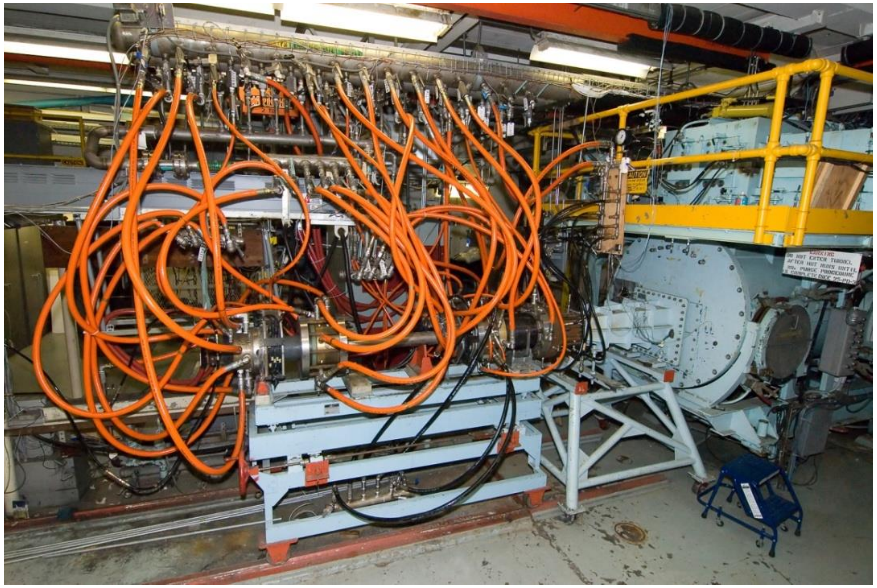
NASA Langley Scramjet Test Complex

AHSTF Dedicated Resources:
- Vacuum sink (4x 60' spheres)
- 20MW Transformer
- Deionized Coolant
- Fuels

Shared Resources:
- High pressure air supply
- Steam ejector
- Staff
- Power (seasonal)
- Coolant (cooling tower)

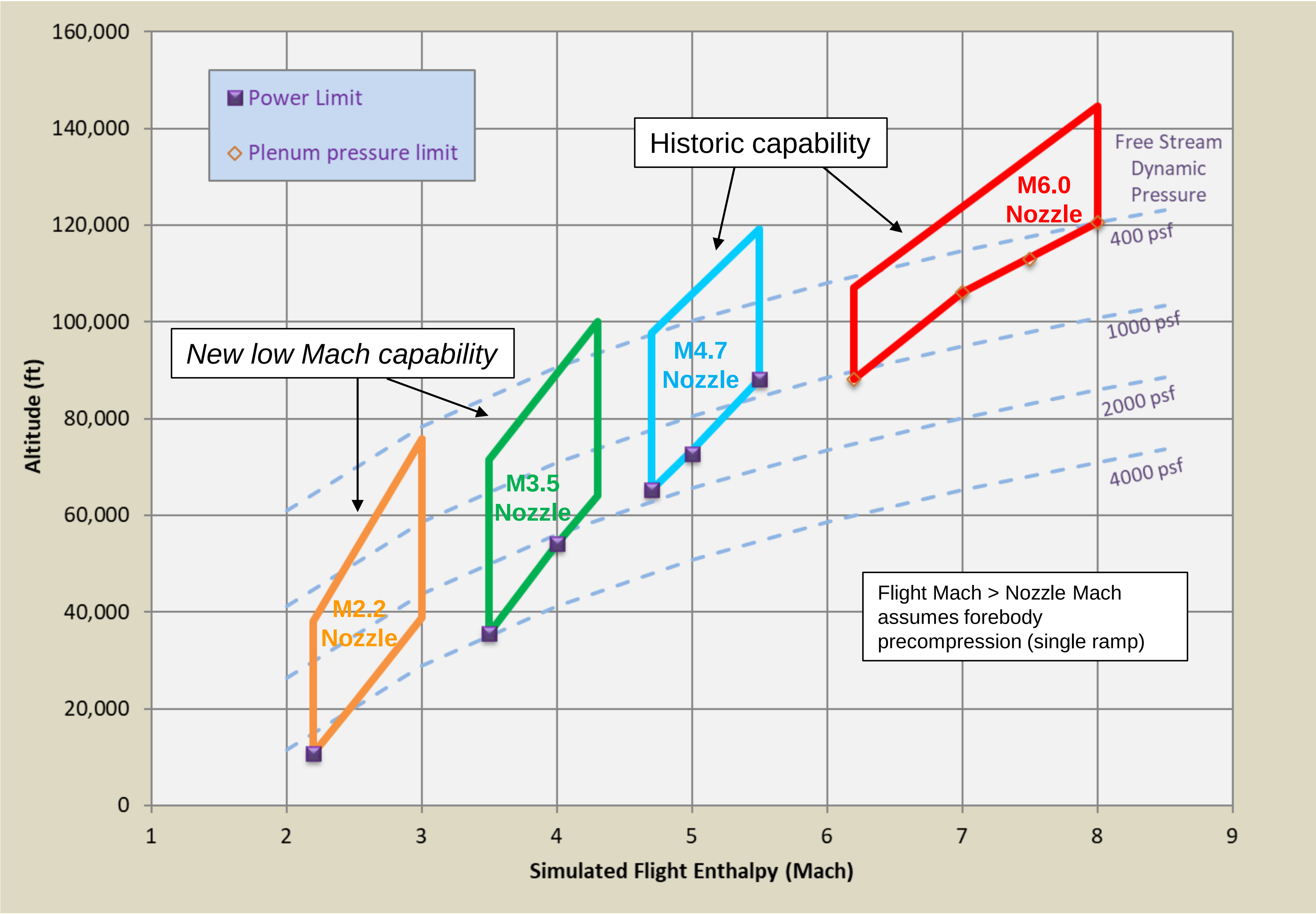
AHSTF Overview

- Security classification levels: Public, SBU, Proprietary, ITAR/EAR, SECRET
- Environment and scale suited for subscale component on up to sub-system level integration tests
- Semifree jet and direct-connect capable
- Fully automated operation
- Arc-heated air (< 1 - 3% NO vitiation)
- Gaseous fuel systems:
  - Hydrogen
  - Silane/H_2
  - Ethylene/Methane mixtures
  - Helium (GH2 substitute)
- Liquid JP fuel system (avail. Spring ’21)
- Run duration and frequency are test-article & test condition dependent:
  - 30-60 sec typical
  - 5 - 10 runs/day typical
  - ***5+ min w/ Mach 6-2D nozzle (Tt = 1664 ^{0}R)***

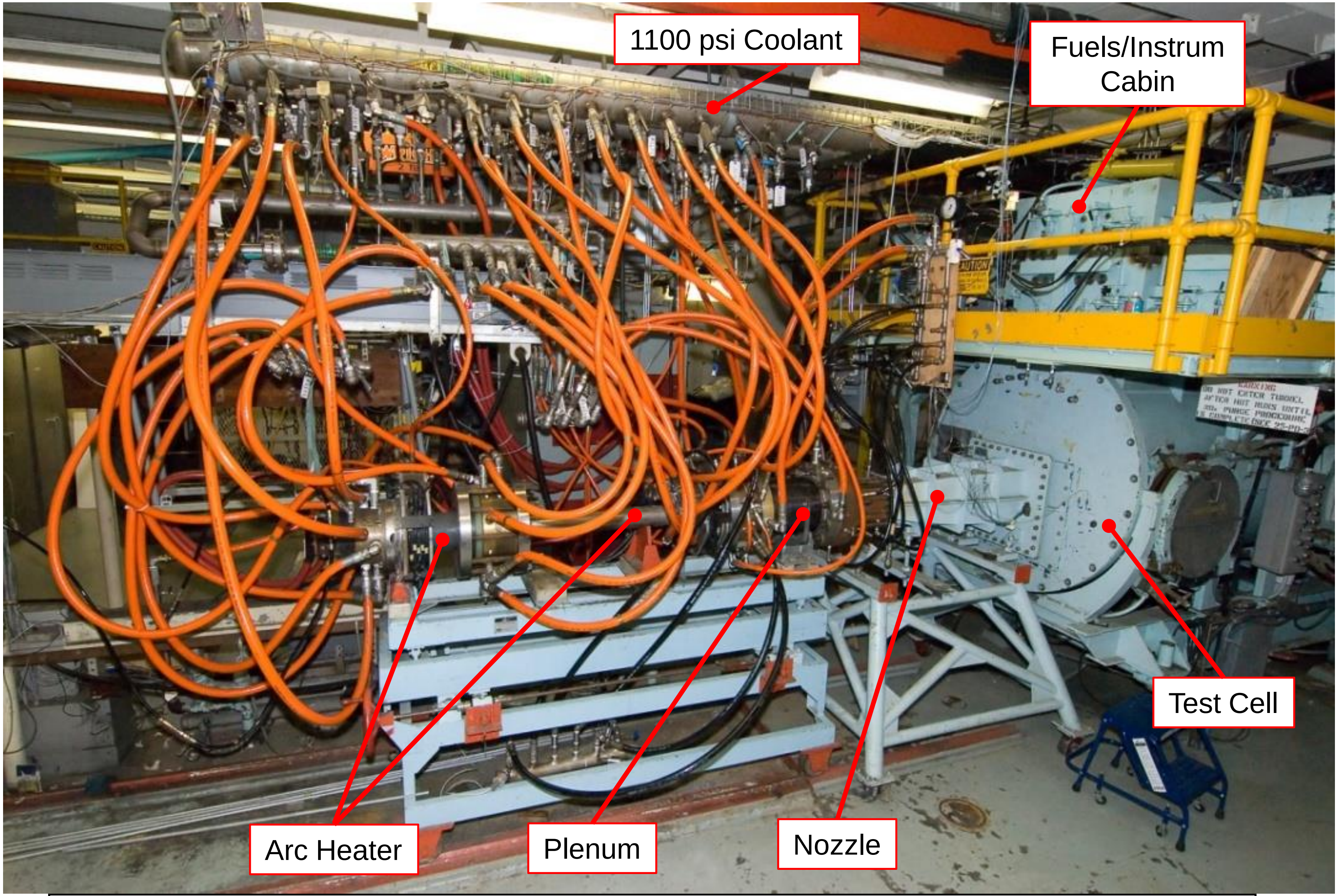


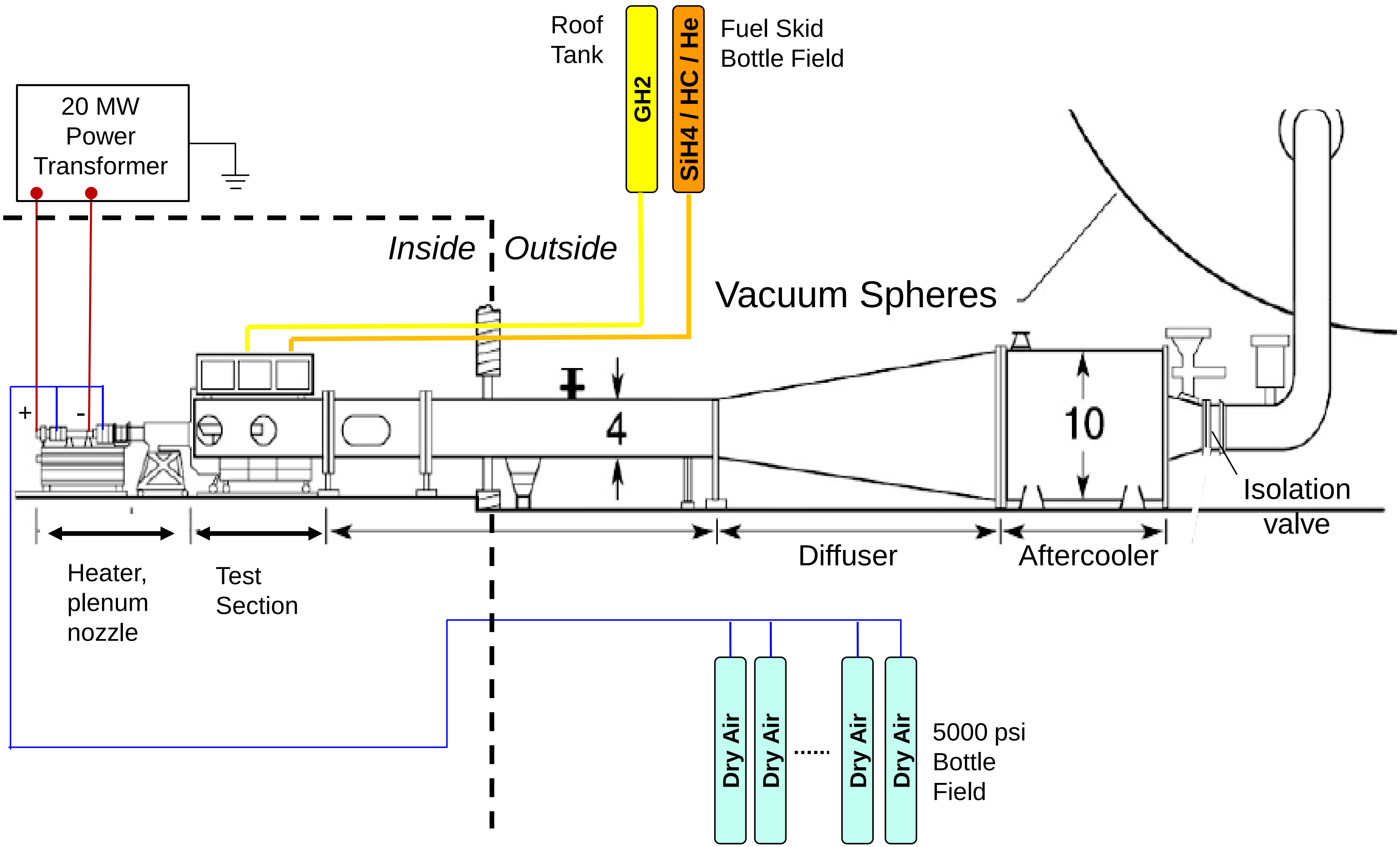
- Total pressure operating limits:
  - 380 psia – Low Mach
  - 625 psia – High Mach
- Flight Mach enthalpy:
  - 2.0 – 4.3 > Low Mach
  - 3.5 – 8+ > High Mach
- Five free jet nozzles: Mach 2.2, 3.5, 4.7, 6.0, and 6-2D

Current Flight Simulation Capability

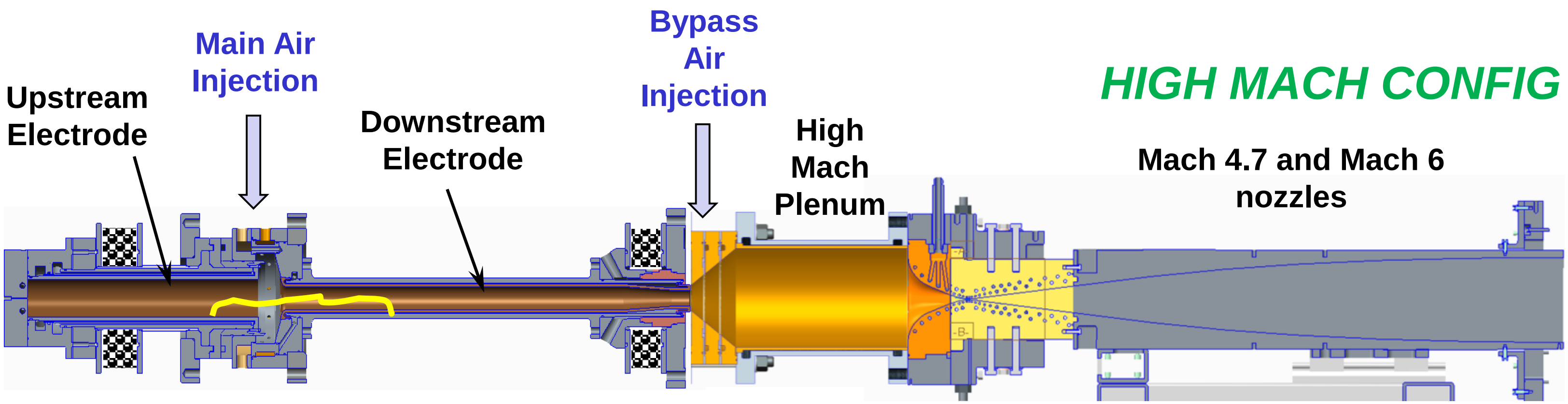


AHSTF Overview

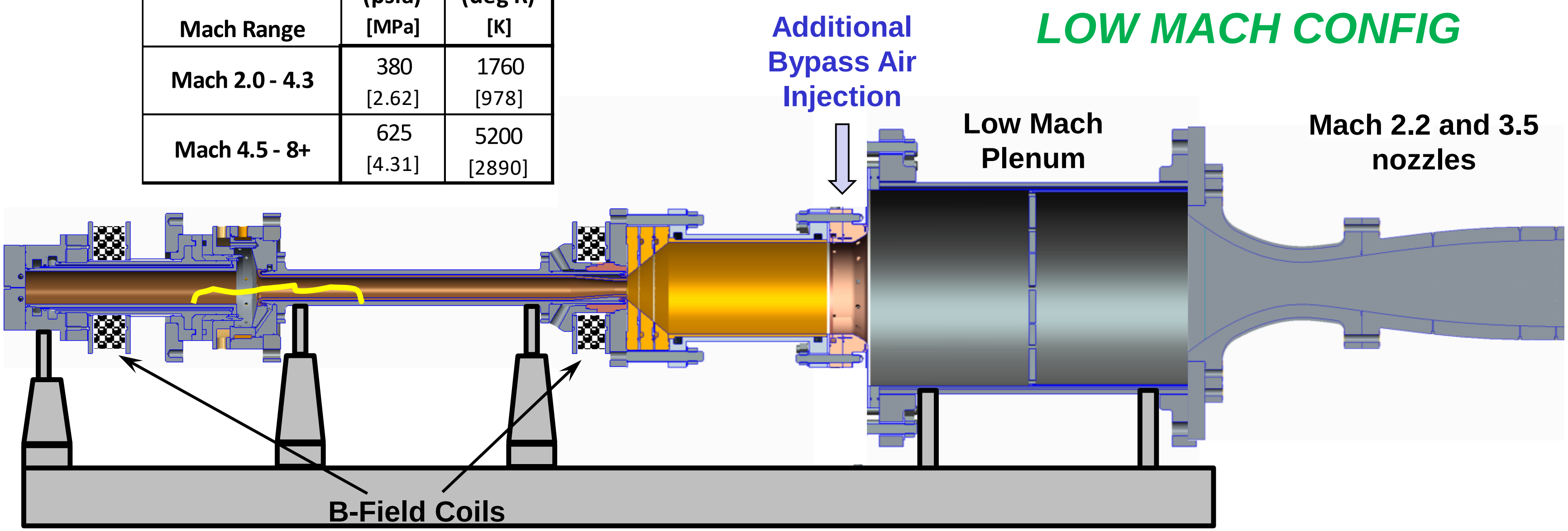



Roof
Tank
GH2
SiH4 / HC / He
Fuel Skid
Bottle Field
20 MW
Power
Transformer
Inside
Outside
Vacuum Spheres
+
-
4
10
Isolation
valve
Heater,
plenum
nozzle
Test
Section
Diffuser
Aftercooler
Dry Air
Dry Air
......
Dry Air
Dry Air
5000 psi
Bottle
Field

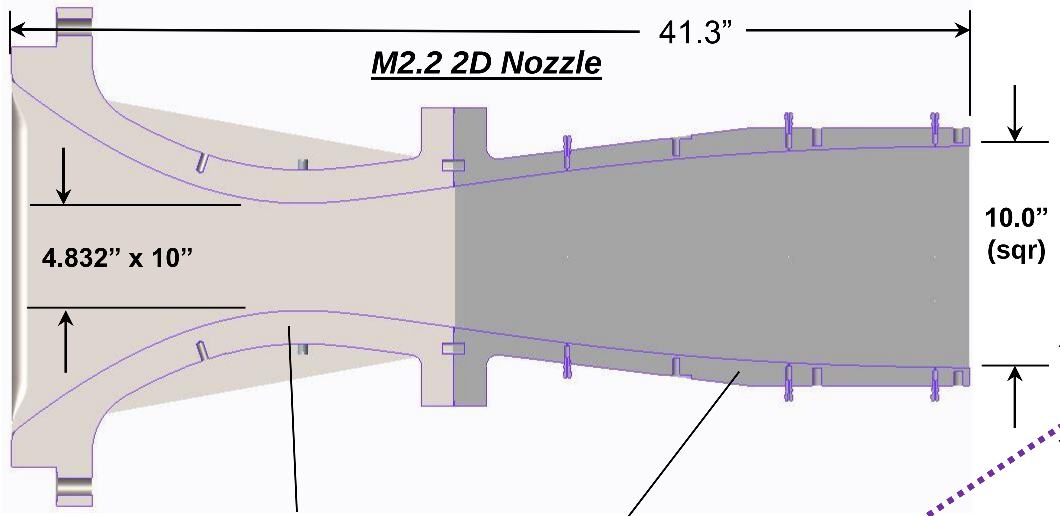
High and Low Mach Configurations

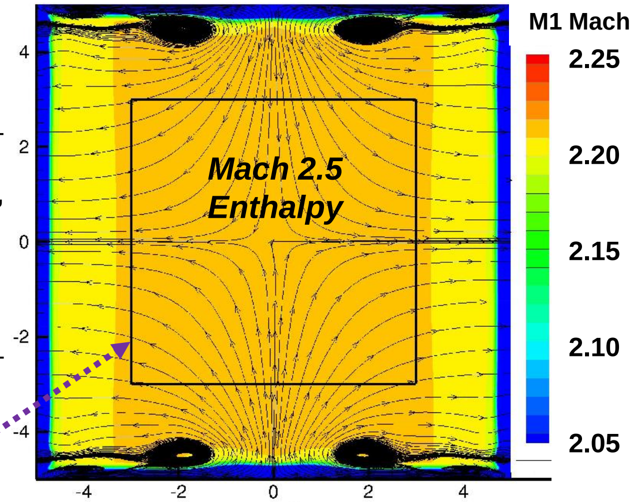


Mach Range	Pt_pln max (psia) [MPa]	Tt max (deg R) [K]
Mach 2.0 - 4.3	380 [2.62]	1760 [978]
Mach 4.5 - 8+	625 [4.31]	5200 [2890]



New M2.2 & M3.5 Low Mach Nozzles



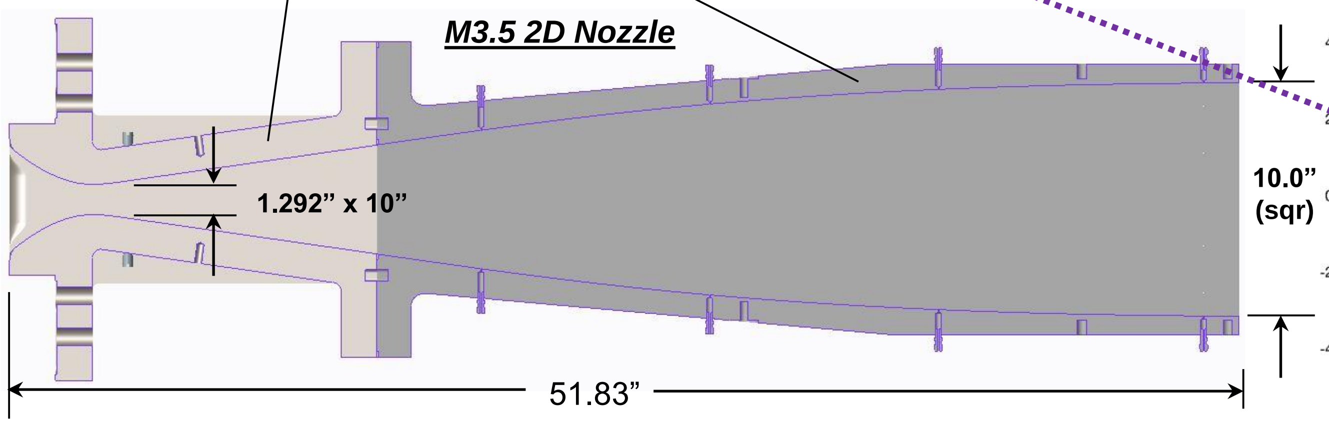


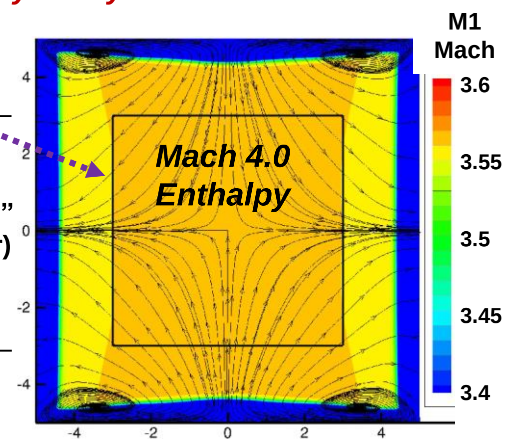
Inconel 625 alloy throats

304 SS Expansions

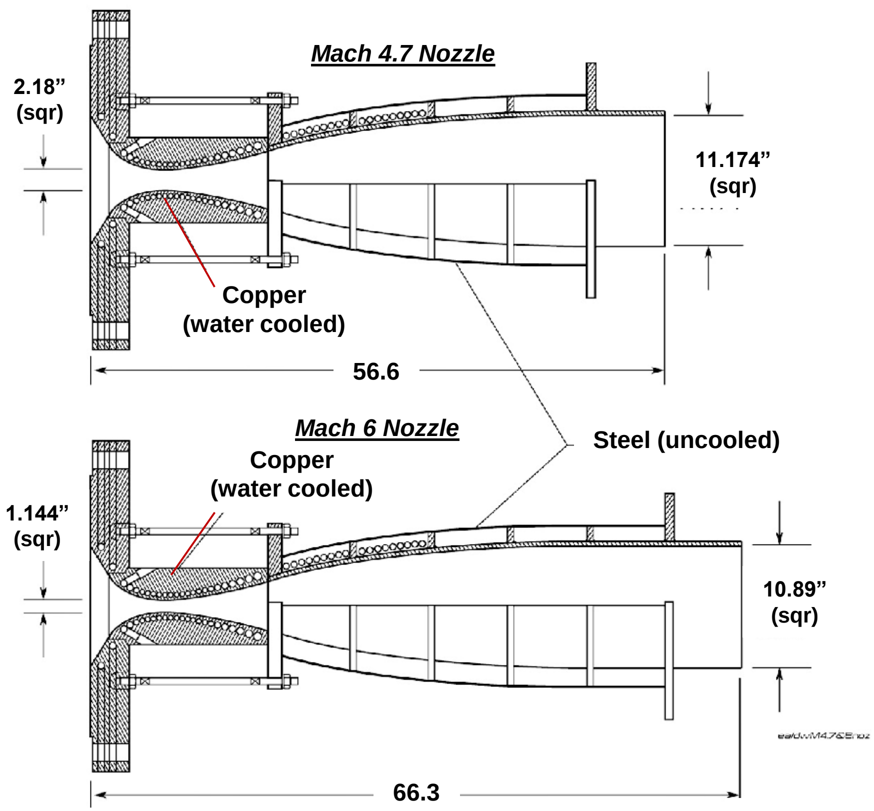
Design Goal

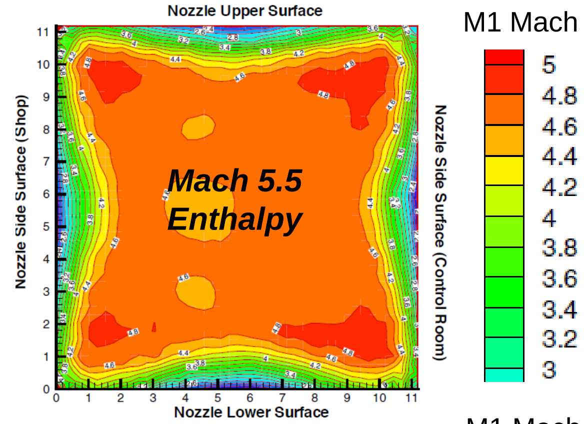
- **Not actively cooled (5 minute run time max)**
- **Completed envelope expansion to M2.4, Tt=840 ºR, q_∞=1850 psf**
- ***Exit flow surveys not yet conducted***

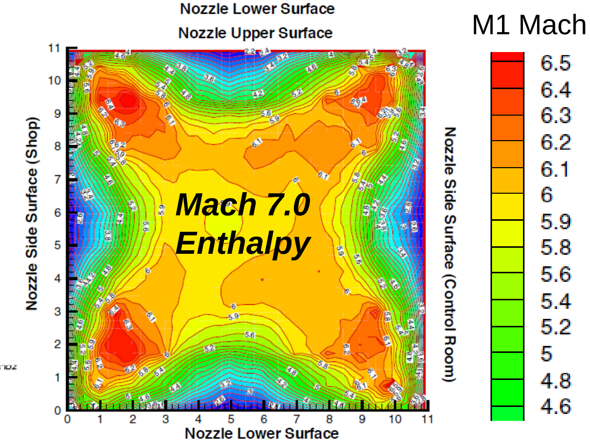




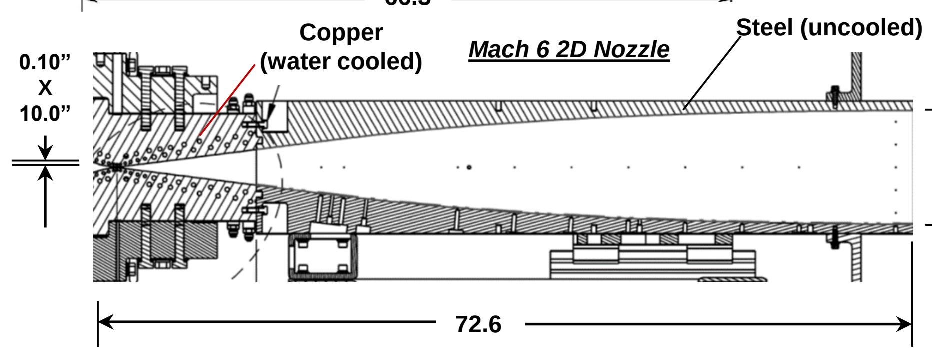
M4.7, M6, M6-2D High Mach Nozzles

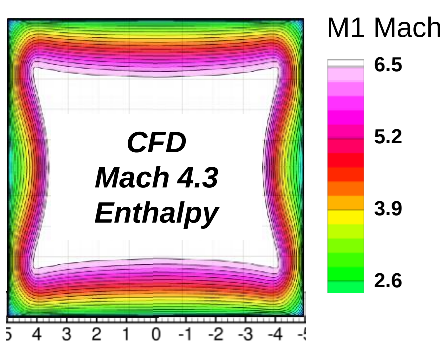






Mach contours derived from detailed nozzle exit surveys *(NASA-TM-2004-213250)*

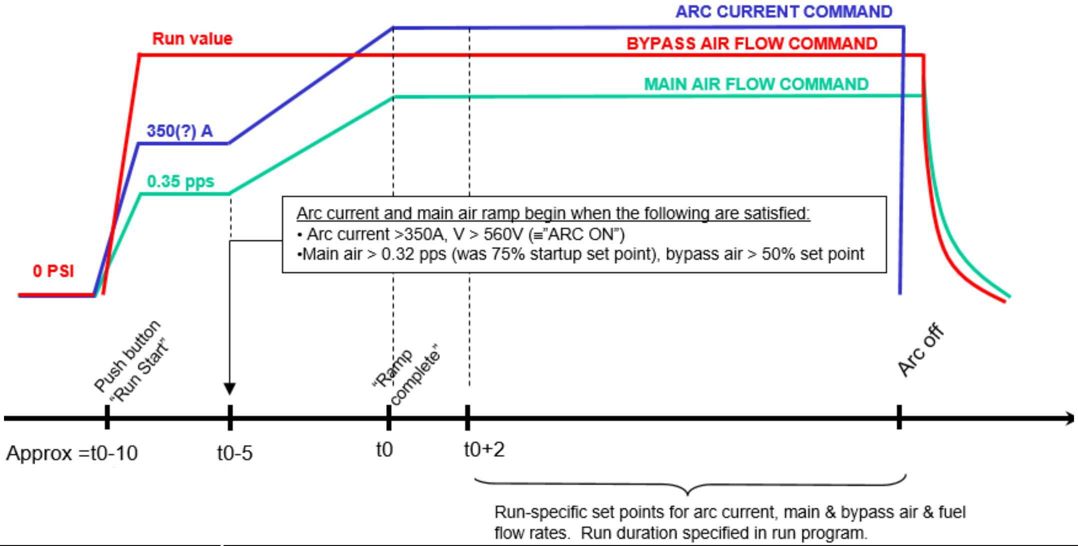


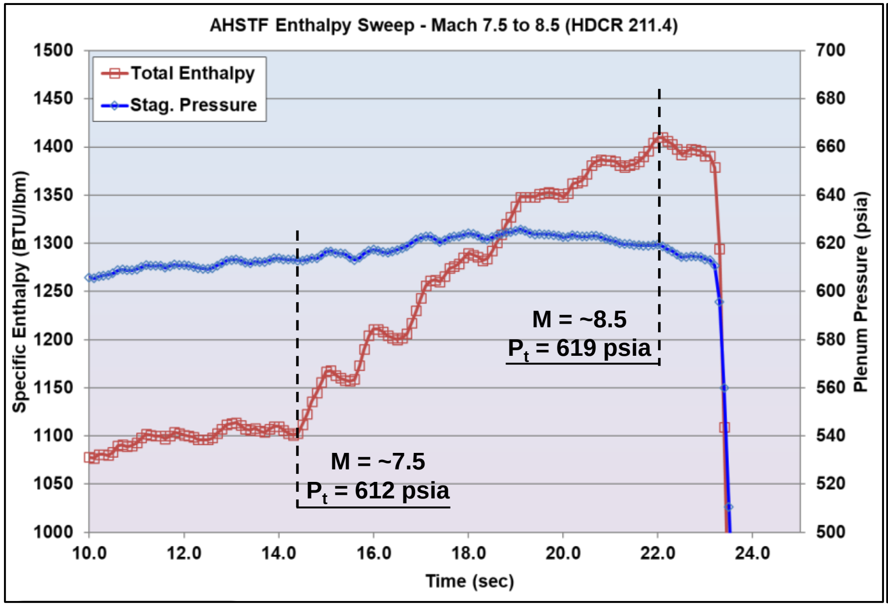


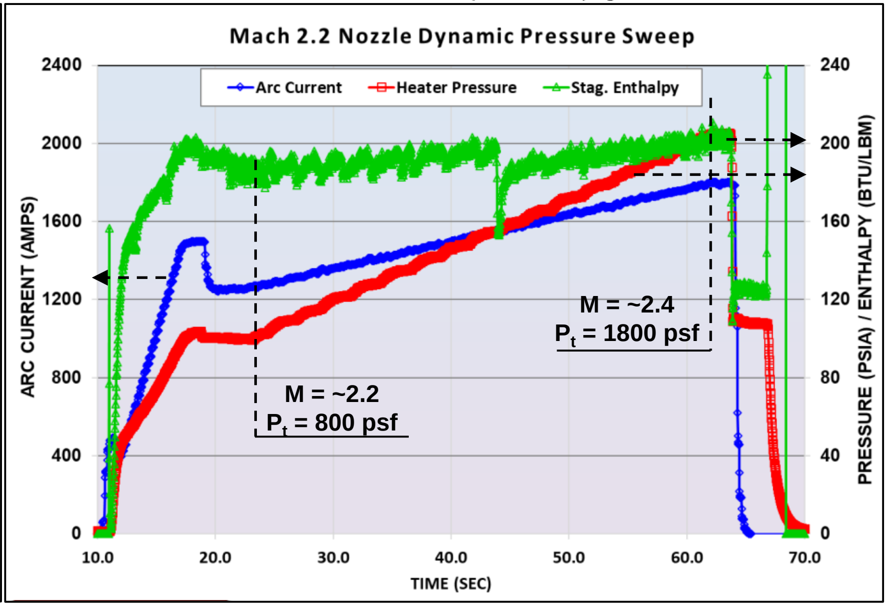
Minimal core flow surveys to date (pretest CFD for reduced Tt test shown)

Facility operation control by Programmable Logic Controller (PLC):

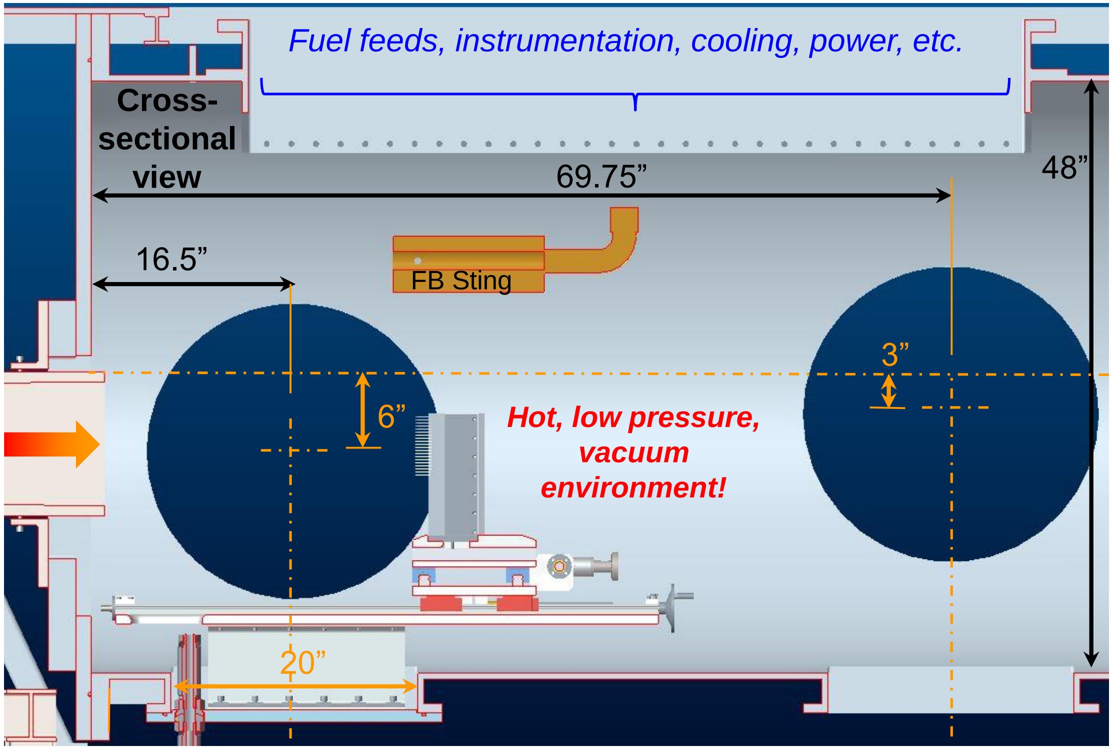
- Fully automated preprogrammed sequence
- Built in interlock and safety checks
- Interfaces available for model controls (4-20 mA, 0-10Vdc, Ethernet, RS-422, RS-232, etc.)
- Steady-state or dynamic operations (18 Hz max)
- Reconfigurable
- >>> Soft start-up process!







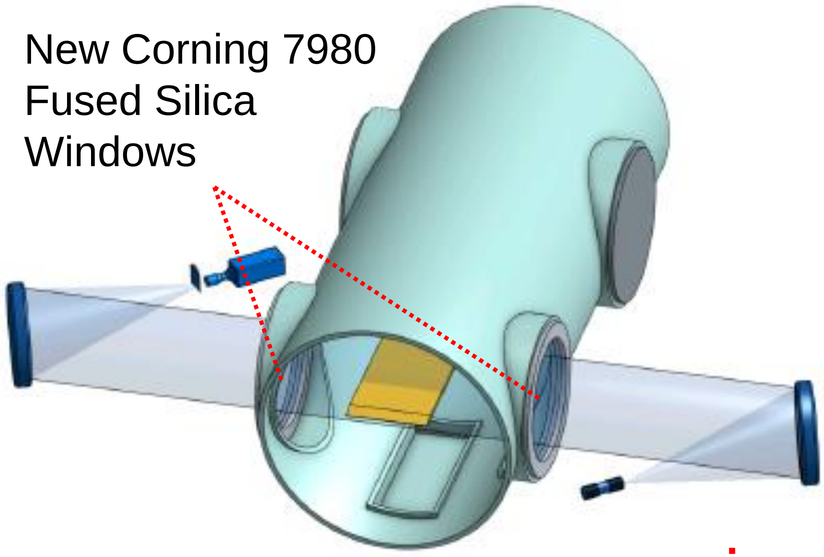
Test Section



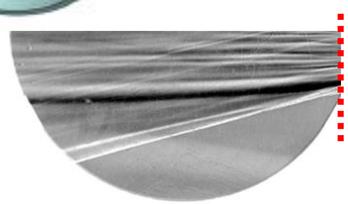
- 48” internal diameter
- Sting mount with 6-component force balance available
- Opposing port doors with optical access
- 20” x 10” lower plate access aligned with port doors
- Fuel systems/splits feed in from overhead compartment
- Instrumentation, power, and cooling available (via multiple access points)
- Rigid mounting at upper rails and floor plates

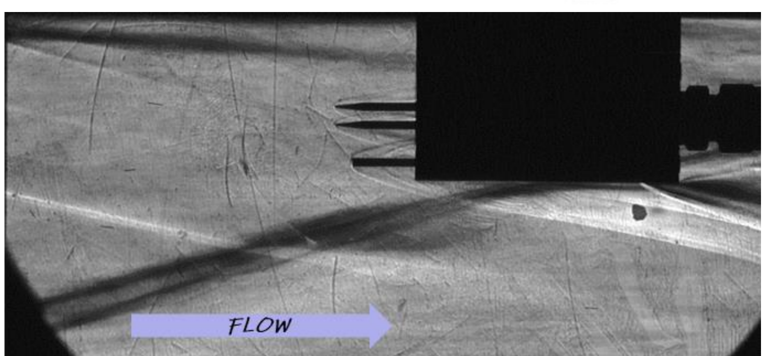
Optical Access

- Opposing 22” dia. optical ports (2 loc.)
- High quality visual / UV laser optical quality
- Corning 7980 Fused Silica Grade UV 0C
  - 2” thick
  - Ti > 99% /cm @ 220 – 1800 nm
  - Surface Quality: 40/20 Both Sides
  - Surface accuracy: 1 Wave over any 12.0” dia.
  - Surface Roughness: 1/10 Wave RMS
  - Parallel: Within 3 seconds



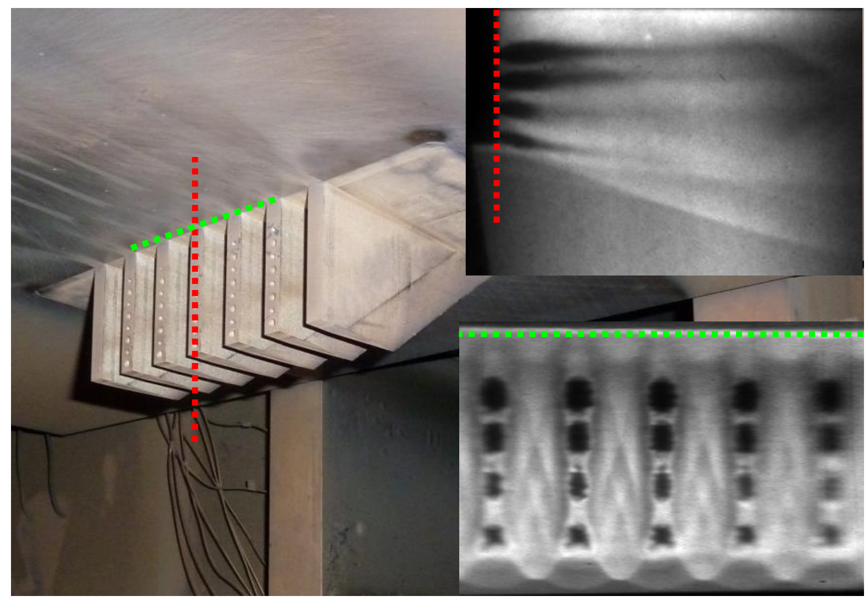
High Speed Schlieren Videography





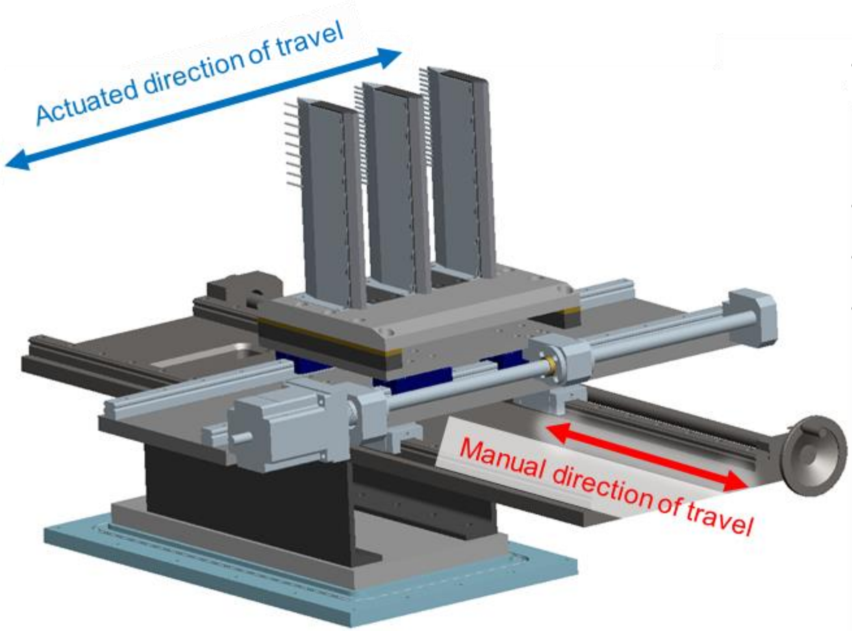
GSAS Demo Rake - Raw Image*, old optics

Planar Laser-Induced Fluorescence (PLIF)

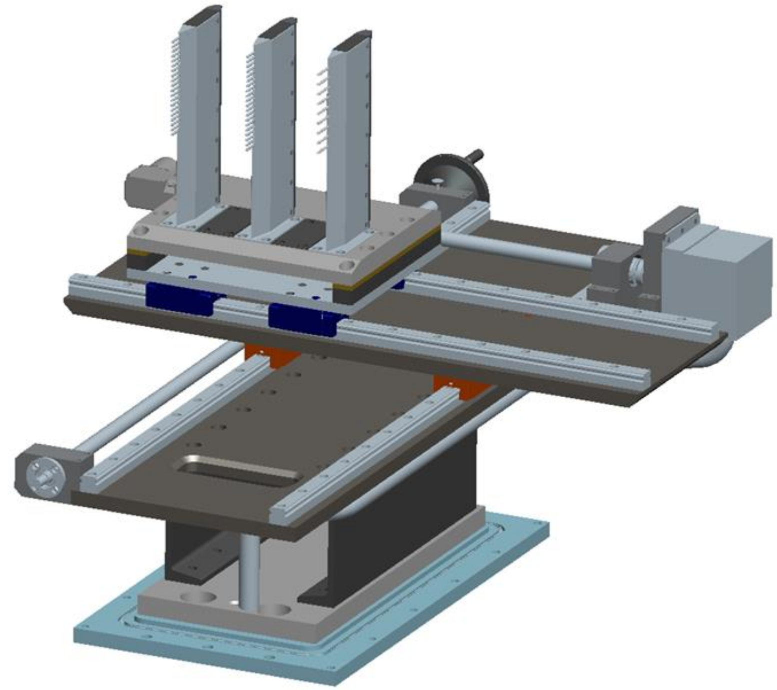


Reference: Drozda et al, JANNAF Dec 2017

Rake Traverse System

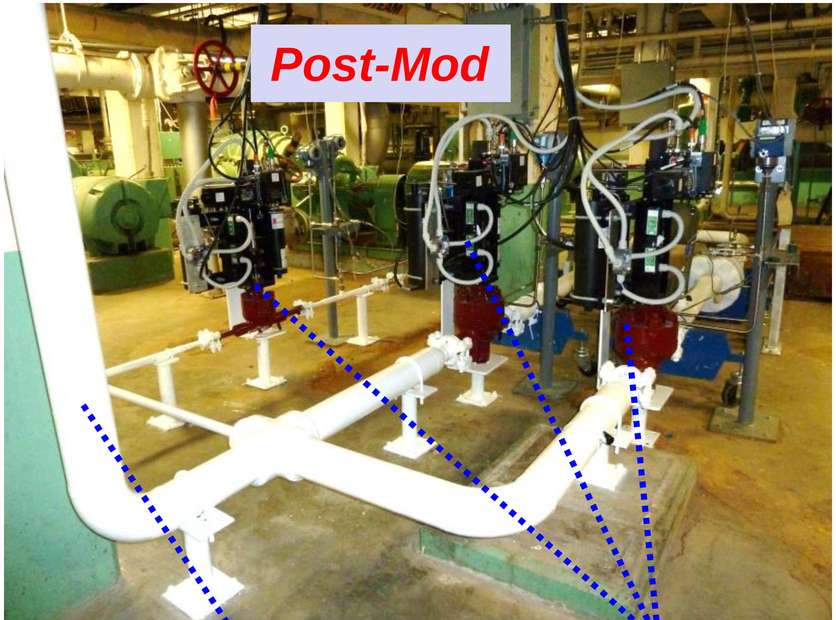


- Remote spanwise active travel control
  - Position accuracy of 0.01” (0.254mm)
  - Translation rates 0-3” (7.6cm) per sec
- Manual axial and vertical positioning
- Tmax = 1760 ºR (978 K)
- Customizable rake/probe/mount assembly



Facility Support Systems

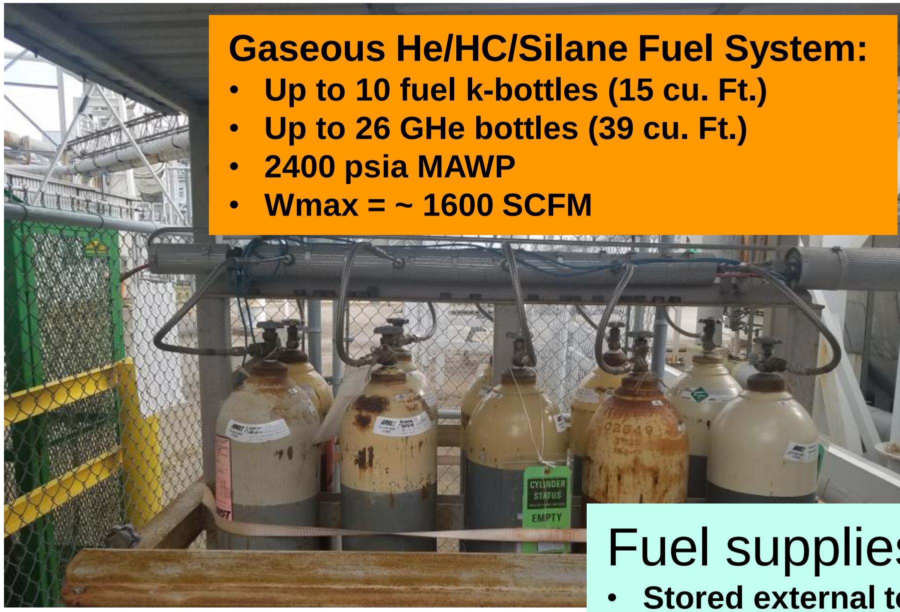
Air Supply System - Upgrades



5k psi lines replaced with larger size (4” vs 2”)

Electraulic Control Valve

- **Wair ~ 90 lbm/sec maximum**
- **Digitally controlled**
- **1” (2.54cm) stroke**
- **0.0005” (0.013mm) positional accuracy**
- **Max slew rate 1” / second**
- **Frequency response – 5 Hz**
- **Closed-loop on flow rate**



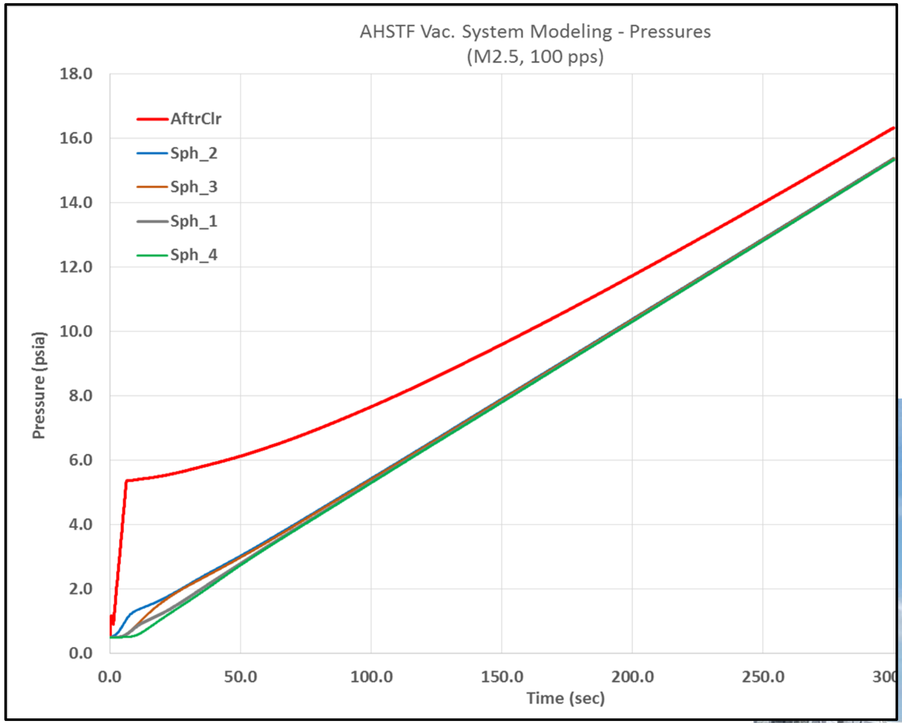
Gaseous He/HC/Silane Fuel System:
- **Up to 10 fuel k-bottles (15 cu. Ft.)**
- **Up to 26 GHe bottles (39 cu. Ft.)**
- **2400 psia MAWP**
- **Wmax = ~ 1600 SCFM**

GH2 Fuel System:
- **31.5 cu. Ft.**
- **4150 psia**
- **Wmax = 10,500 SCFM**

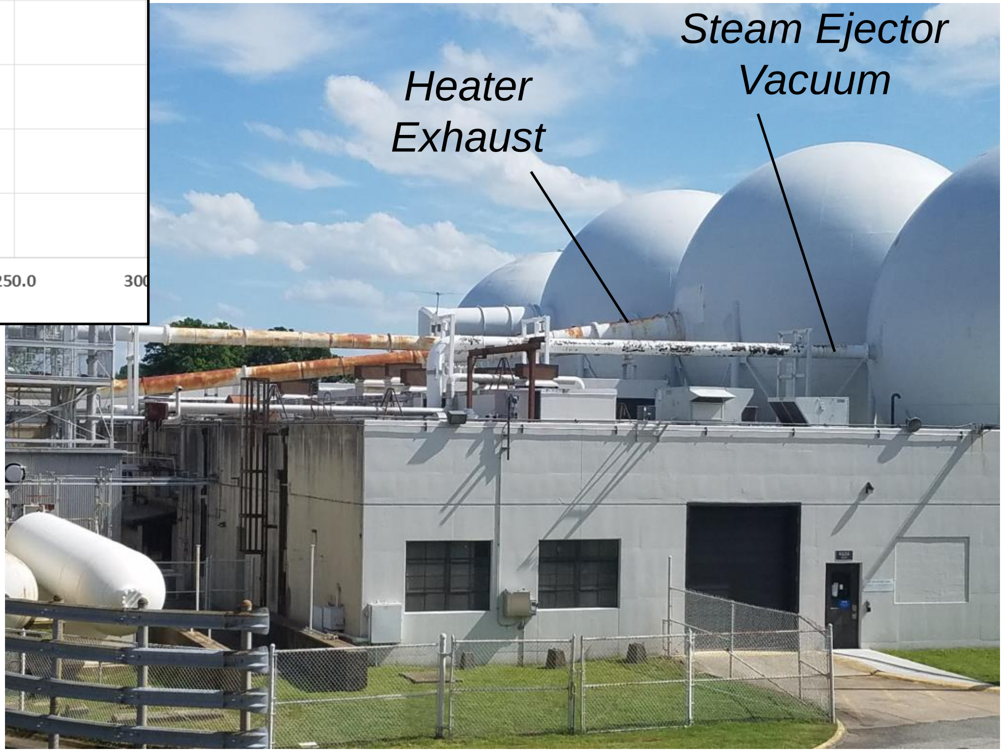
Fuel supplies are:
- **Stored external to facility**
- **Exposed to the elements**

Liquid JP System:
- **Fabrication (Jan. ’21)**
- **90 Gallons Storage**
- **1600 psi MAWP**
- **32 GPM max**

Vacuum System



- 4 – 60’ spheres dedicated to the AHSTF
- Single (shared) 350# class steam ejector evacuation system
- Pull down time between runs dependent upon post run sphere pressure
- Verified design meets operations across full range



NOTE – The steam ejector is the only approved means of vacuum generation for the facility due to NOx contamination issues.

Pacific Scientific 6000 Series

FEATURES Mounting for 16 input/output modules providing up to 128 channels expandable to 4096 channels

- **High-speed IEEE-488 interface for control and data**
- **Optional PCM telemetry and SCRAMNet data output**
- **Fast hardware-based alarms with digital outputs**
- **2M sample ring buffer for event capture**
- **Built-in fans and cable tray**

http://www.pacificinstruments.com/index.html

Initium ESP Control & Data System

- 512 channels simultaneously with up to 8 different pressure ranges
- 1200 Hz / channel scan rate
- 10/100 Base-T Ethernet Interface
- Interfaces with Pacific 6000 series

ESP Pressure Scanners

- Thermally compensated pressure scanners (0 – 80 ºC)
- +/- 0.03% FS accuracy (> 5 psid)
- Scan rates up to 70k Ch/sec
- Inventory of 32-port modules includes:
    - 2x – 5 psid
    - 2x –15 psid
    - 2x - 30 psid

https://www.te.com/usa-en/product-CAT-SCS0010.html?q=Initium&source=header

Summary & Future Plans

The latest improvements to the AHSTF have enhanced it's value as an experimental platform for investigating and maturing hypersonic propulsion system components and technologies.

- New expanded facility operating envelope of M2.0 – M8+
  - Increased air mass flow delivery to 90 pps
  - New Mach 2.2 and 3.5 nozzles
  - Envelope expansion successfully completed with Mach 2.2 nozzle up to q_∞=1850 psf, Mach 2.4 total enthalpy
- Successful integration and test of Rake Traverse System for nozzle calibration and test article flow surveys
- Successfully demonstrated dynamic trajectory capability

Future developments/activities:

- Complete current testing for Enhanced Mixing & Injection Project (‘20 - ‘21)
- Integration and verification of liquid JP fuel system (Spring ’21)
- Free jet test of proprietary inlet design (Spring ’21)
- Direct-connect test of hydrocarbon fueled ramjet (Summer ‘21)
- Aether high speed flowpath tests (Fall ‘21)

POCs

Facility Manager:
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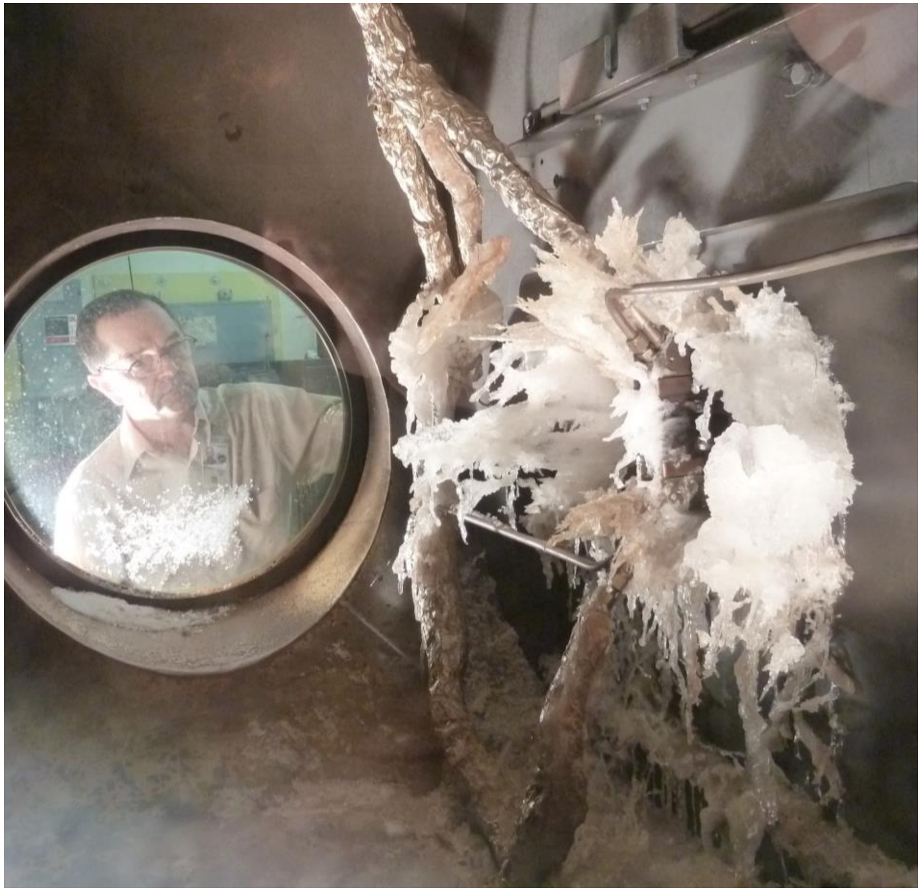
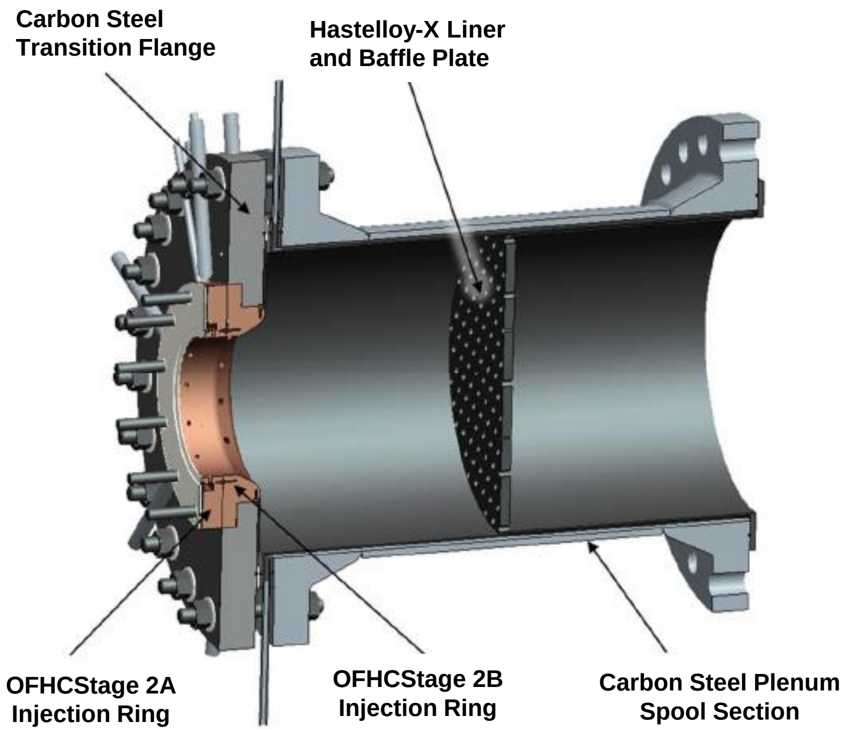
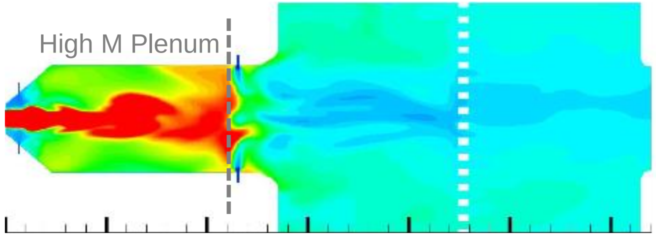


Questions?

Low Mach Plenum (M2 – M4.3)

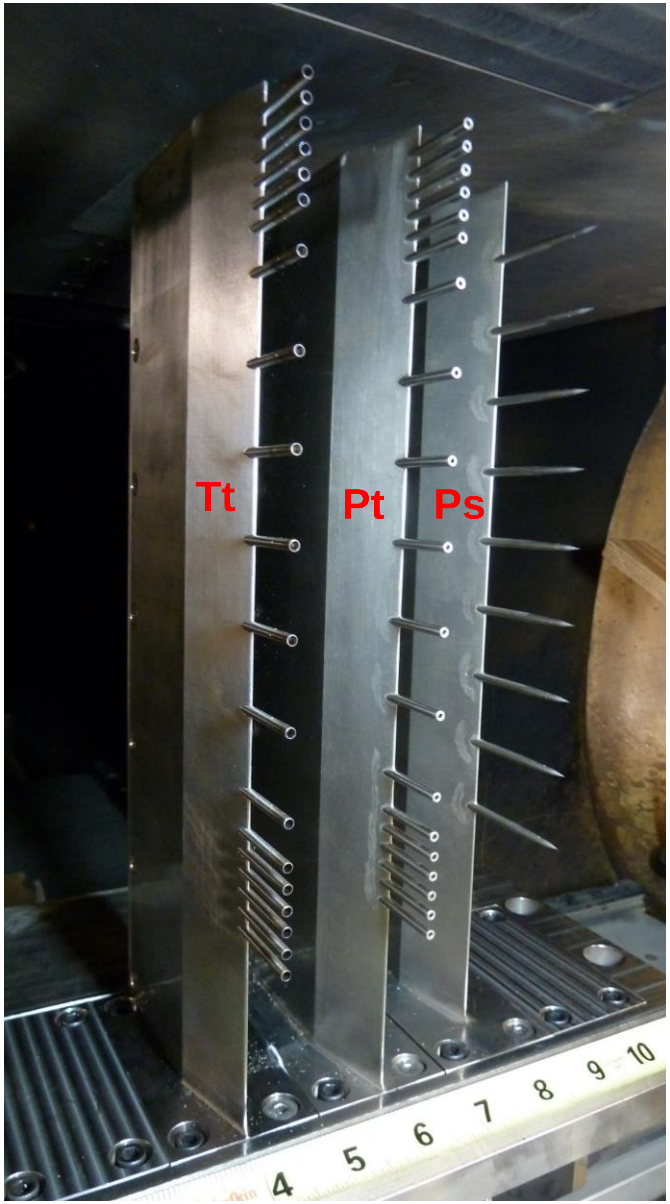


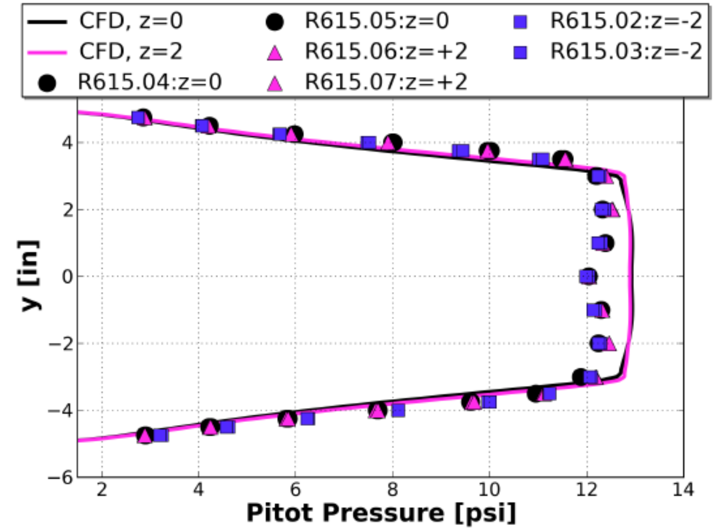


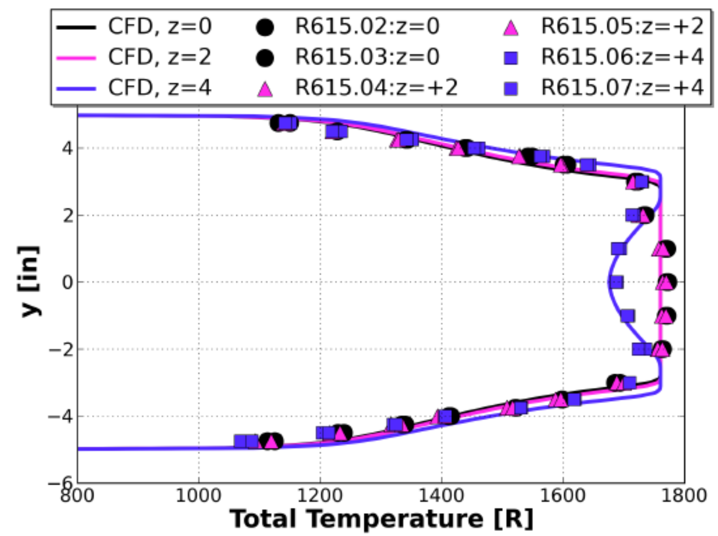
CFD M2.2 @ 4 pps - Gas Temperatures

Larger plenum extension facilitates:
- Additional air mass injection
- Increased nozzle throat entrance areas
- Proper hot/cold air mixing and settling for stagnation conditions

M6-2D Nozzle Exit Core Flow Quality







First nozzle surveys of this nozzle ever, and it was at off-design Tt (M = ~4.3).

Reference: Drozda et al, AIAA SciTech 2017