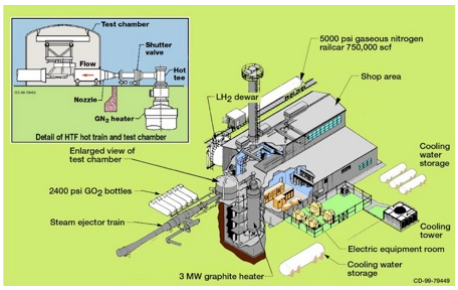
What makes Plum Brook Station Unique

- 2700 hectares total/2200 fenced
  - Secure site with securable data and facilities
- Staffed and equipped for
  - Large scale cryogenic tests in harsh conditions
  - Extreme temperatures, pressures, noises and vibrations
  - Explosives and hazardous materials storage
- 100 megawatt power grid
  - Affordable power (vs commercial rates) on day shift
  - High MW tests on site don't affect local users
- Large scale availability of gas, water and sewer
- 90 km from large airports (Cleveland, Mansfield) and 8 km from deep water Lake Erie port (Huron)

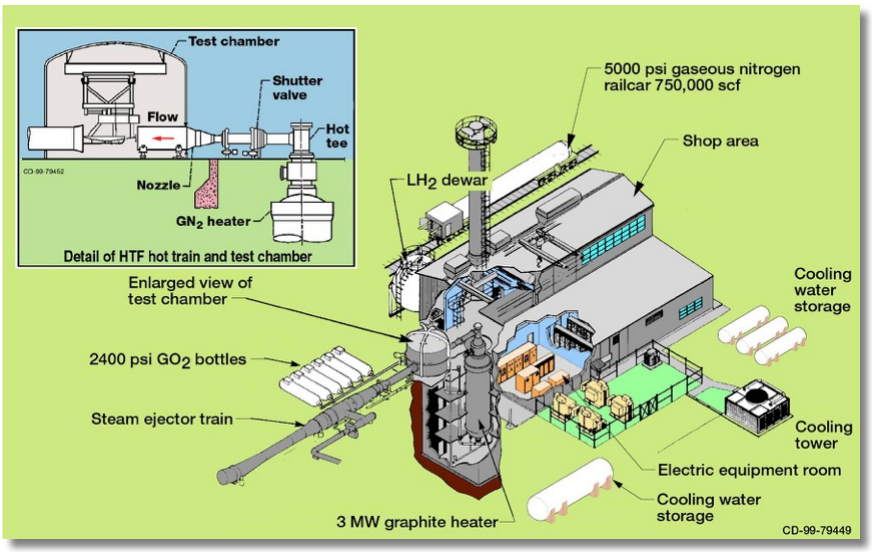
Hypersonic Test Facility (HTF)



- **HTF is the United States' only large scale, non-vitiated (clean air) hypersonic test facility**
  - **1.1m diameter x 4.3 meter long test section**
  - **Run times up to 5 minutes at maximum flow rate**
  - **Capable of Mach 5, 6, 7 flows in either free-jet or direct connect modes**

- **This facility provides basic hot-flow test capabilities**
  - **Large scale hot-gas rocket nozzle testing (ambient or altitude up to 3900m)**
  - **Materials testing**
  - **Communications through ionized flows for Entry, Descent, Landing**
  - **Hybrid gas electric propulsion for aviation**
  - **Hypersonic sensors, propulsion, airframe/engine integration**

HTF Systems Overview



HTF Test Capability

- **Direct Connect Testing (Mach 1.5 to 4+)**
  - 113.4 kg/s ~ 4 minutes
  - 22.7 kg/s ~ 20 minutes
- **Freejet Testing up to Mach 7: ~4.5 minutes**
  - Mach 5, 6, & 7 free-jet nozzles
- **HTF Individual System Capacities:**
  - Nitrogen Rail Car - 24948 kg of N_2 @ 31 MPa supply
    - (17.2 – 86.2) kg/s ~ (4 – 20) minutes
  - Oxygen Vessels – 15422 kg of O_2 @ 15.2 MPa supply
    - (5.4 – 27.2) lb/s ~ (9 – 45) minutes
  - HTF Heater - ~ 27215.5 kg PGX Graphite @ 2500 ˚K
    - ~ 52,752.8 MJ stored
    - 113.4 kg/s test flow
      - Mach 4: ~5.5 minutes
      - Mach 3.5: ~10 minutes
      - Mach 3: ~18 minutes
      - Mach 2.5: ~30 minutes

Test Considerations

- Test Chamber is a domed cylindrical structure 7.62 m diameter, 6.1 m in height
  - Model lengths of 4.27 m can be accommodated
- Thrust stand (single axis) for free-jet testing
  - Designed for a test article up to 7,257.5 kg in weight and 3,855.5 kg thrust
  - Potential for 76.2 cm translation and 5˚ AOA; model can be injected (swung into position)
- Dedicated, stand alone, state of the art data system
- Support Systems:
  - **Fuel**: Systems previously used include Liquid JP-10, Gaseous Hydrogen, Methane, Natural Gas
  - **Hydraulics:** 20.7 MPa, 128.7 lpm
  - **Inert Gases**: nitrogen purge up to 27.6 MPa
  - **Water**: De-ionized cooling water nominally 37.9 lpm @ 6.9 MPa & 4,542.5 lpm @ 2.76 MPa; raw water back-up
  - **High Pressure Air:** 0.69 MPa service air
  - **Electrical Power:** ~ 10 MW available
  - **Flammable Gases:** Previously tested Hydrogen, Silane, and Natural Gas

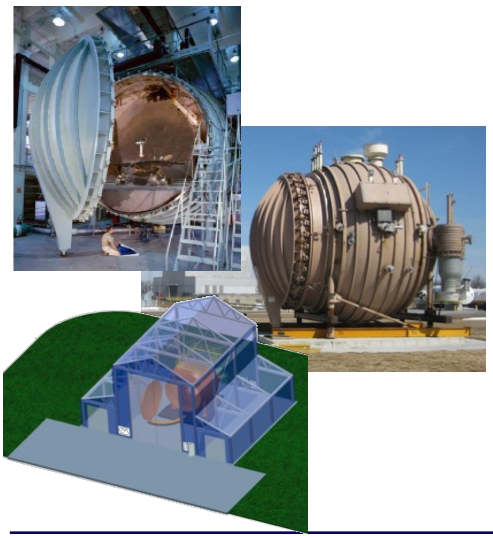
High Flow Thermal Facility Hot Train

View of flow path for heated GN2 from the storage heater below deck, through the oxygen injection and GN2 diluent sections, providing precise mixture ratios and temperature control, to the expansion nozzle and altitude chamber (background).

Combined Effects Chamber (CEC)

Planet/Planetoid Space Simulation

Recently relocated, CEC helps rule out problems in space surface environments



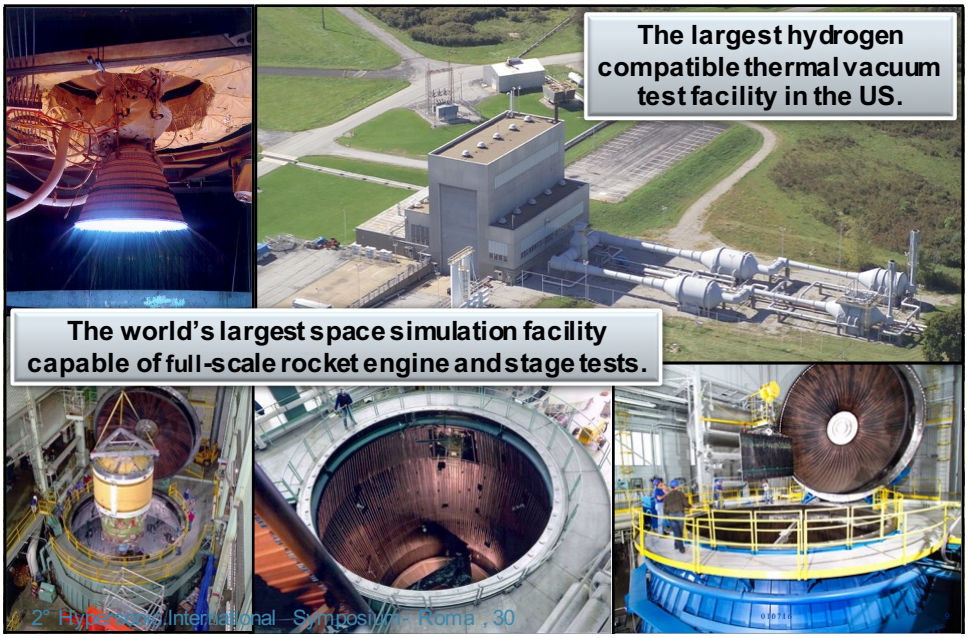
KEY FEATURES

- Large size (25' dia. Spherical chamber)
- Vacuum capability (10-8 torr)
- Liquid hydrogen cold wall (40K temps)
- It can accommodate regolith simulant in the chamber, including stratification for drilling & excavation demonstrations
- Built-in shaker system that can be used for settling and stratification
- Simple design makes chamber inexpensive to maintain and operate

SYSTEMS AND COMPONENT TESTING FOR:

- Landers (robotic and human)
- Rovers (robotic and human)
- In-situ Resource Utilization (ISRU) systems
- Surface power systems
- Heat radiators and deployment systems
- Surface habitats
- EVA systems
- And much more

NASA Glenn Research Center
Spacecraft Propulsion Research Facility (B-2)



B-2 Facility Capability Summary

(all values are approximate and for reference only)

Rocket Test Capability with Vacuum Start

(assumes LH2/LO2 props*)

10K lb Thrust Engine for 380 sec Test Duration
100K lb Thrust Engine for 270 sec Test Duration
300K lb Thrust Engine for 20 sec Test Duration
500K lb Thrust Engine for 5 sec Test Duration
* Other propellant combinations are possible

Space Simulation

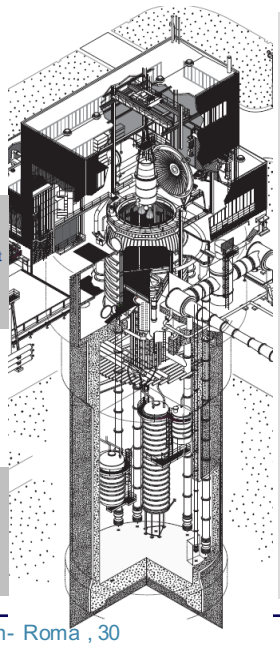
Test chamber is capable of vacuum space soak at $5x10^{-8}$ torr with -320°F cold wall and 130w/ft^2 radiant heating. Uses mechanical and oil diffusion pumps to achieve vacuum conditions. Facility LN2 capacity is 200gal/min (cold wall uses 100gal/min).

Physical Dimensions

Test Chamber Clear Space	33ft dia x 55ft high
Top Entrance	27ft dia
Diffuser	11ft dia x 37ft long
Spray Chamber	67ft dia x 120ft deep

Exhaust System

Maximum capacity of 120 lbs/sec Dry Air Equivalent (DAE) at 1psia using a three stage intercondensing steam ejector consuming 348 lb/sec of steam. Produces ~0.14 psia in spray chamber with 40°F water.



Data Systems

- 576 channels of analog inputs
  - Up to 1 kHz Bandwidth/channel (4 kS/sec)
  - Resolution: 24 bits rounded to 16
  - +/- 0.1 to +/- 10 volts in 1,2, & 5 steps
  - Dynamic range > 88 dB (measured at input > +/- 1 volt)
- 32 channels high speed analog inputs
  - Up to 97.2 kHz Bandwidth/channel (256 kS/sec)
  - Resolution: 24 bits rounded to 16
  - +/- 0.1 to +/- 10 volts in 1,2, & 5 steps
  - Dynamic range > 88 dB (measured at input > +/- 1 volt)
- 32 channels discrete I/O (TTL)
- 2.5 Terabyte RAID 5 Storage, redundant, mirrored recording
- IRIG-B time stamped Data and Video
- 6 Customer Data Display screens available for real time display, calculations, plots

Space Power Facility (SPF)

One-of-a-kind environmental testing capability at ONE location:

- Vacuum Chamber:
  - … the largest space simulation chamber in the world
  - ✓ 800,000 ft^3 volume, 100 foot diameter, 122 feet high
  - ✓ Ambient to 10^{-6} Torr vacuum capability
  - ✓ Features variable geometry cryogenic shrouds
  - ✓ 7 MW power available for solar simulation
  - ✓ Reverberant-mode EMI/EMC test capability
- Reverberant Acoustic Test Facility (RATF):
  - … the most powerful reverberant chamber in the world
  - ✓ Capable of reaching an overall sound pressure level of 163 dB
  - ✓ 101,000 ft^3 volume, 37.5 ft x 47.5 ft x 57 ft high
  - ✓ 36 acoustic modulators and horns for highly-tailored spectrum-shaping
- Mechanical Vibration Facility (MVF):
  - … the highest capacity shaker system in the world
  - ✓ 18' diameter shaker table
  - ✓ 75,000 lb test article (1.25 g's vertical, 1.0 g's horizontal)
  - ✓ Frequency range: 5 - 150 Hertz
  - ✓ Sinusoidal testing in 3-axis without removing test article

Recent history

2005 – Funding for PBS zeroed, closure likely
2006 – Funding restored
2007 – SPF chosen for Orion testing
2007-11 -- $130M of upgrades at SPF
2011 – B-2 thermal vacuum chamber operational
2013 – SpaceX is first user of new RATF
2015 – ESA Service Module STA arrives
2016 – Mechanical Vibration Facility operates

How did the good things happen?

- Principles: Honesty, Humility, Housekeeping, Hospitality, Health
- Honesty: we tell the truth, especially if we erred
- Humility: we do not have all the answers
- Housekeeping: we keep our common areas clean
- Hospitality: we value visitors and we have 3000 per year
- Health: we strive for safe, effective and reliable operations

Summary

-Any technical area cannot prosper without
  - Relevant data taken in appropriate conditions
  - Thorough understanding of human behavior
  - Focus on the long term
  - Support for the efforts of others
- Success in hypersonic research demands that we find w
- There is a way if we allow ourselves to do so