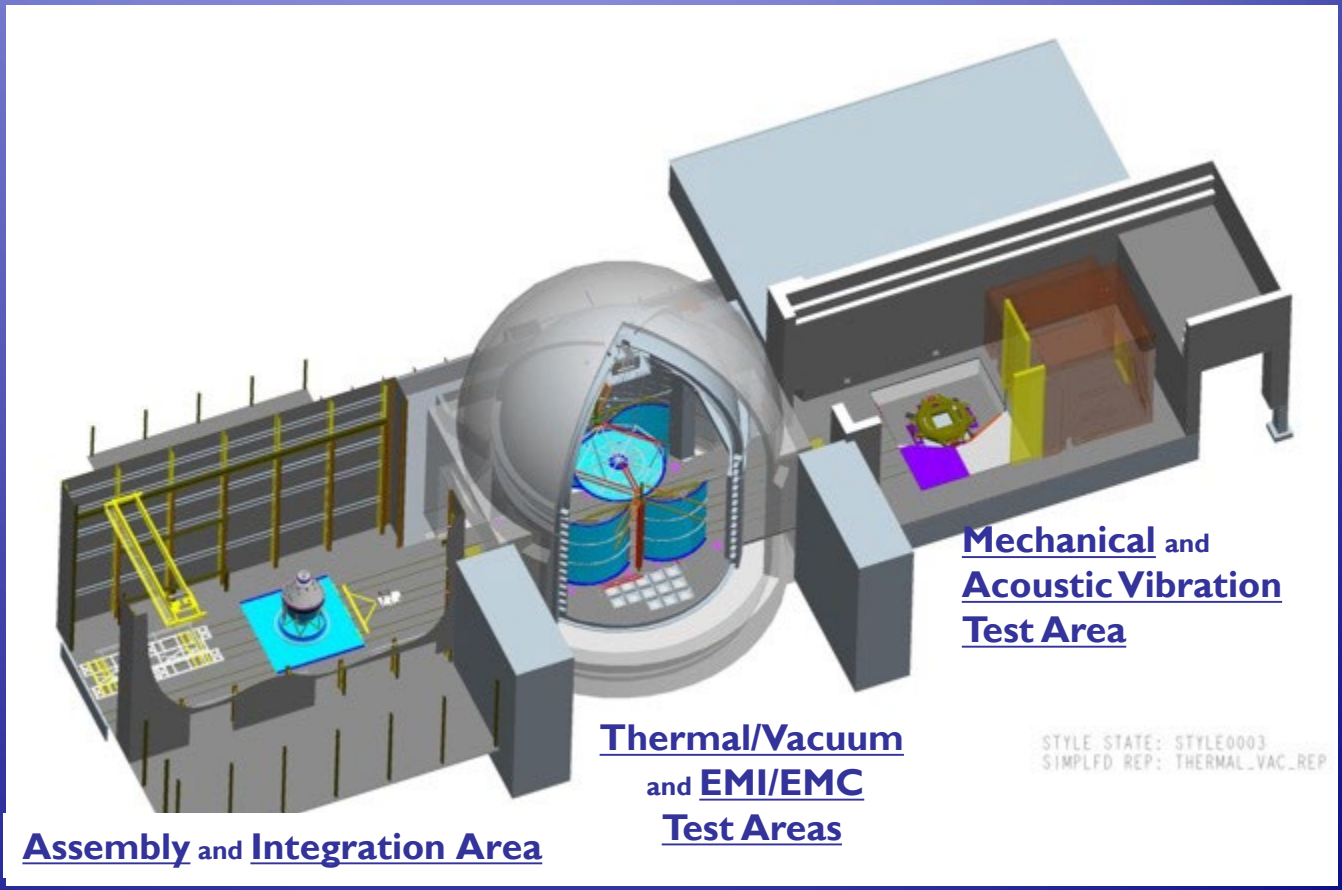
Space Environments Complex (SEC)

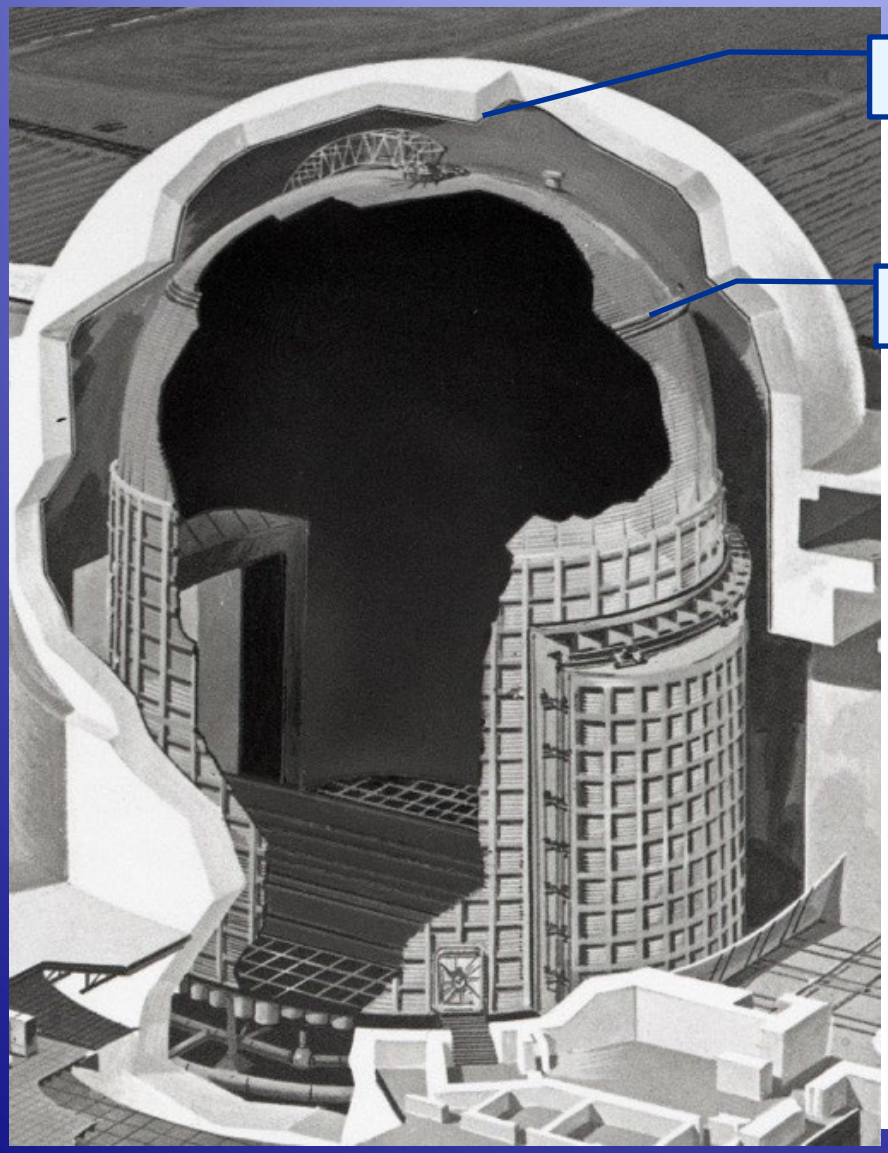


Space Environments Complex Testing Facilities

- Space Power Facility – Space Environment Simulation Chamber
- Reverberant Acoustic Test Facility
- Mechanical Sine-Vibration Facility
- Reverberant-mode EMI/EMC
- Modal Plate



Space Environments Complex
Thermal Vacuum Chamber



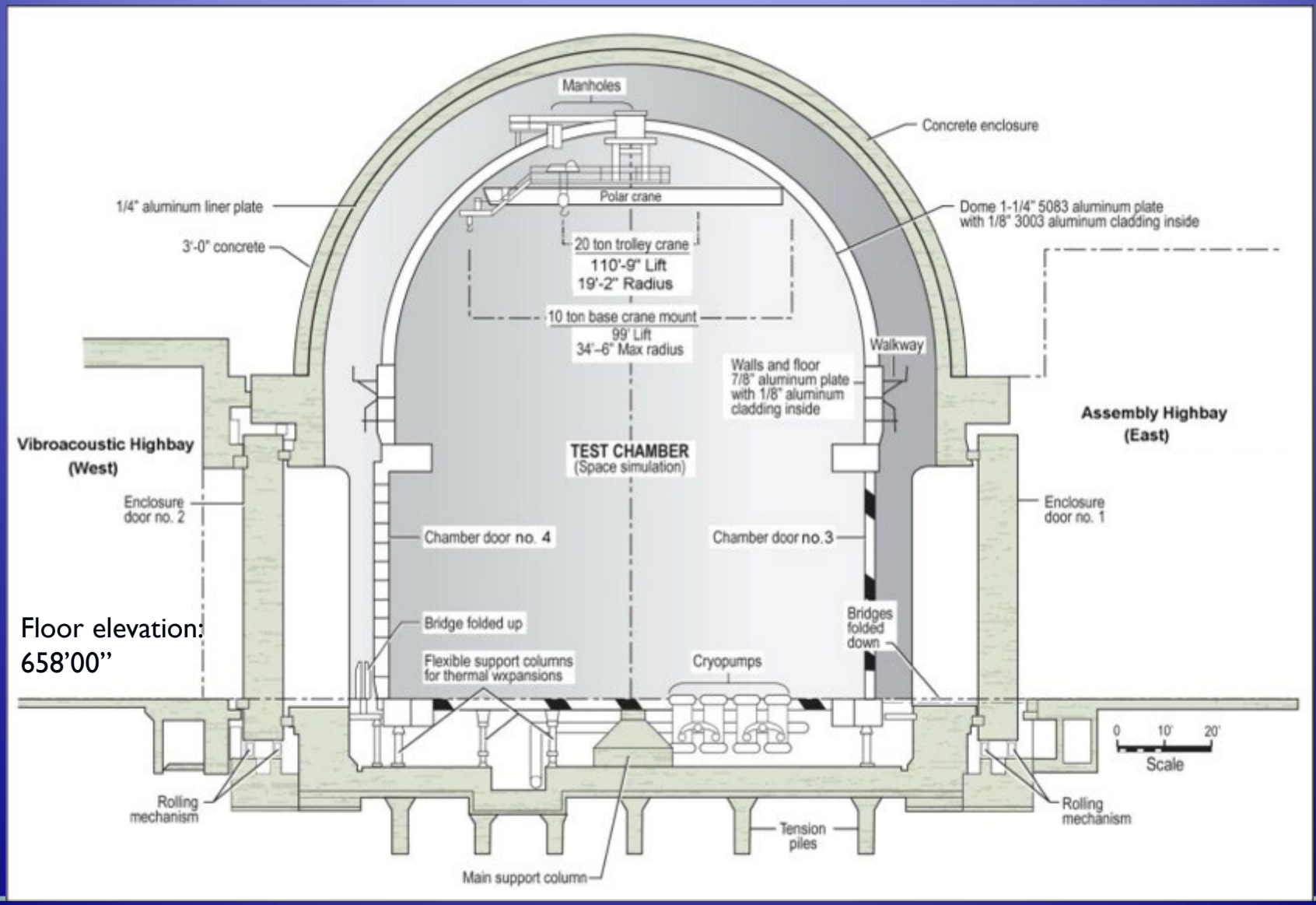
Low-Vacuum Concrete Chamber

- Primary Pressure Vessel
  - 6-8 foot thick concrete with steel liner for vacuum
  - Operated at 15-20 Torr (0.5 psia)

High-Vacuum Aluminum Chamber

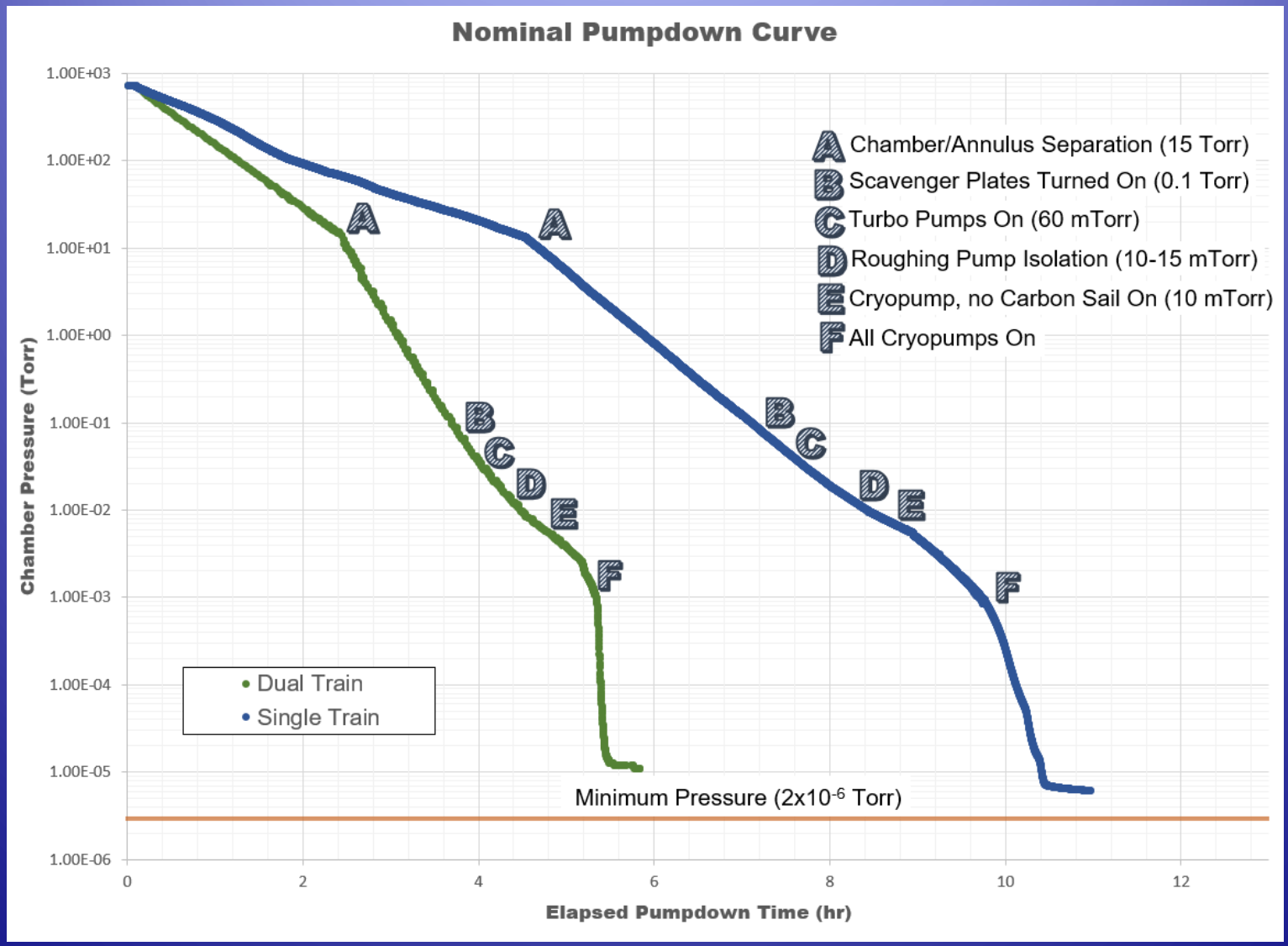
- Physical Characteristics:
  - Chamber Volume: 100 ft (30.4 m) diameter x 110 ft (33.5 m) height (to Polar Crane)
  - Standard Electrical Feedthroughs
  - Polar Crane: 20 ton, 10 ton (auxiliary hoist)
- Parameters:
  - Test Pressure: <1E-5 Torr
  - Shroud Temperature: --160 to +80 °C (-260 to +180 °F)
  - Chamber Pumping: Roughing pumps, turbomolecular pumps, cryopumps
- Integral Instrumentation:
  - Pressure: Baratron, capacitance manometer Atm to 10-3 Torr
  - Ion Gauge: 10-3 Torr to ultimate
  - Payload Temperature: 800 Type-T Thermocouples
  - Contamination Monitor: TQCM, Scavenger Plates, Residual Gas Analyzer

Vacuum Chamber Cross-Section

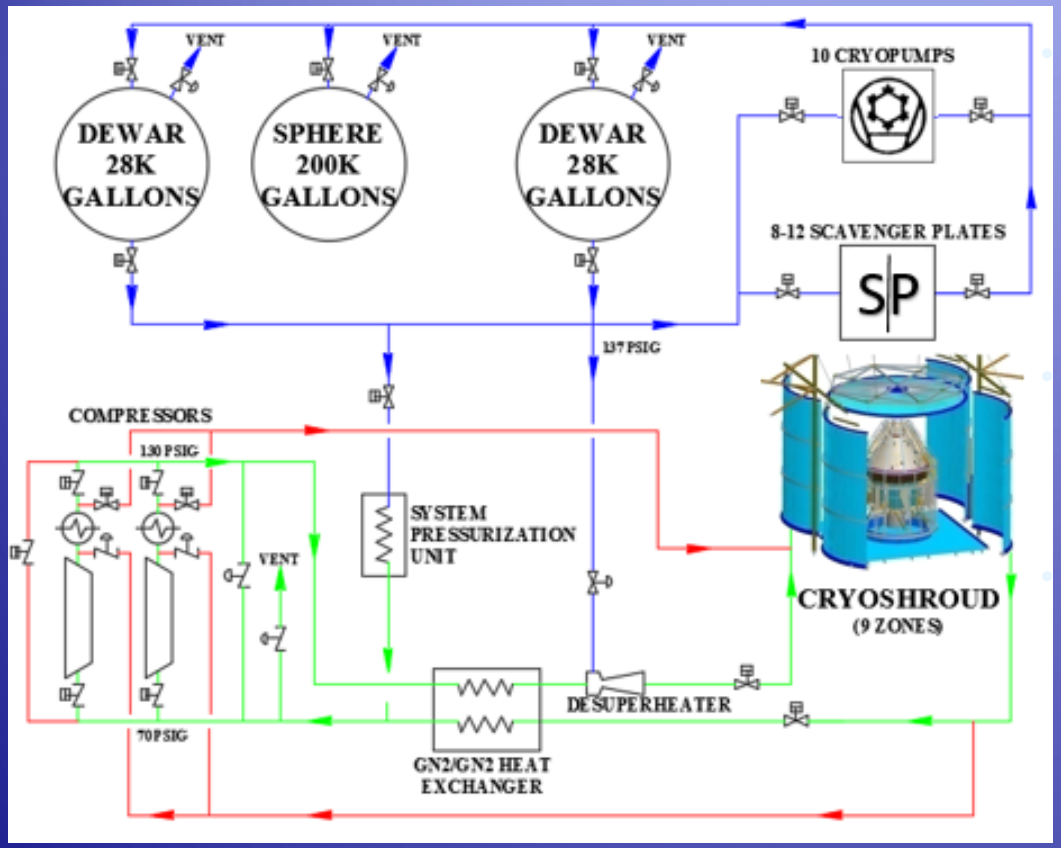


Floor elevation:
658'00"

Vacuum Chamber Nominal Pump Down Curves



Cryogenic Cryoshroud System



Liquid Nitrogen
Hot Nitrogen Gas
Cold Nitrogen Gas

Liquid nitrogen circulates through cryopumps and scavenger plates in a semi-closed loop system

- Two 28,000 gallon Liquid Nitrogen Dewar (150 psi) can supply nitrogen to system
- Additional 48,000 gallons can be provided via rental

Cryoshroud Temperatures is controlled between -255°F to +175°F (-160°C to +80°C)

- Rate of change 0.75 °F /minute nominal

11,000 CFM compressors circulate gaseous nitrogen through cryoshrouds

- Liquid nitrogen injection into gaseous nitrogen stream allows temperatures from ambient to minimum
- Bypassing heat exchanger allows temperatures from ambient to maximum





Heat Flux System Power Capabilities

Power Level	Zones (channels)	Voltage (V)	Current Limit (A)	Type of Control
15 kW	32	125 DC	120	Voltage Level
2.4 kW	40	100 DC	24	Voltage Level
1.2 kW	36	120 AC	15	SCR Zero Crossing
200 W	6	20 DC	10	Voltage Level
50 W	5	120 AC		Thermostat
~36 kW annulus only	2	120 AC		SCR Phase Angle, Open Loop

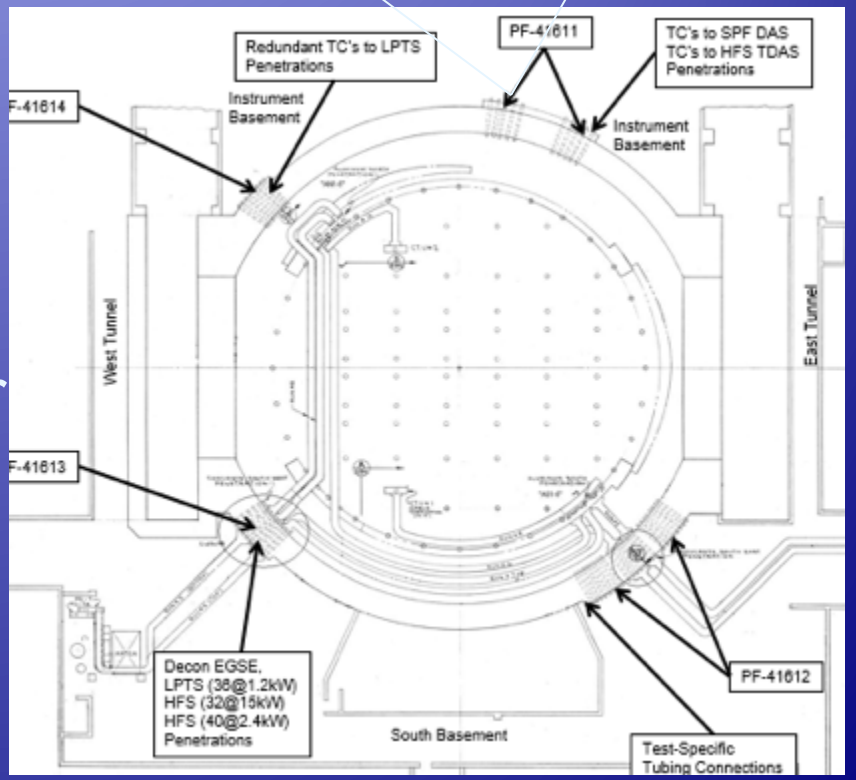
Instrumentation/Control Penetrations

Description	Quantity
Type T thermocouple	1464
Type E thermocouple	112
RTD	16
37-pin connectors (MIL-DTL-5015 Arrangement 28-21)	60
7-pin connector (MIL-DTL-5015 Arrangement 24-10)	16
3-pin connector (MIL-DTL-5015 Arrangement 28-22)	2
BNC coaxial connector	96
Ethernet	13

Instrumentation Feedthroughs

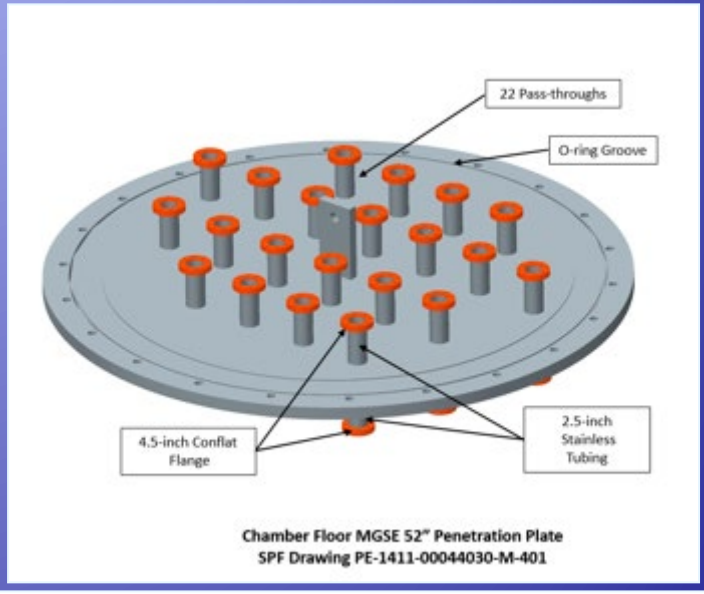
- Harnesses for instrumentation have two chamber penetrations:
  - Concrete Chamber Wall – chamber wall feedthrough has a "gooseneck" feed through 14 feet in length through wall (shown) – feedthroughs in basement
  - Aluminum Chamber Wall – can be located at or above the chamber floor (floor above basement)
- Feedthroughs on aluminum chamber should be vacuum-rated
- Typical total harness lengths: 200+ feet (60+ m) long



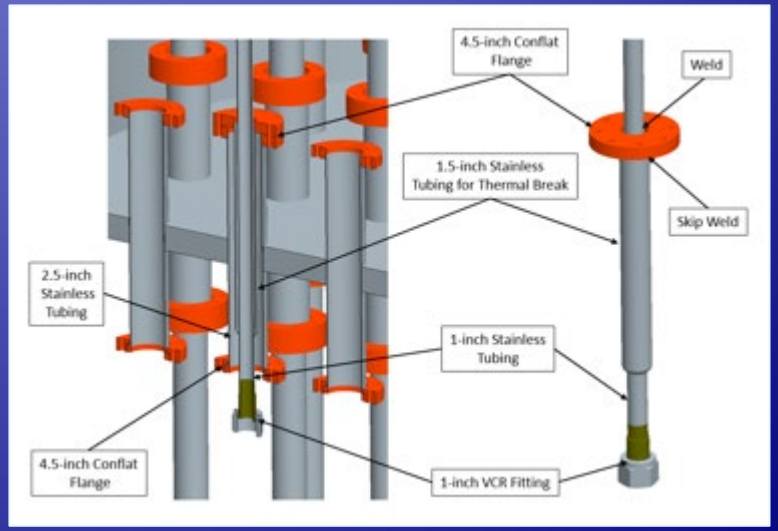


Fluid Connections

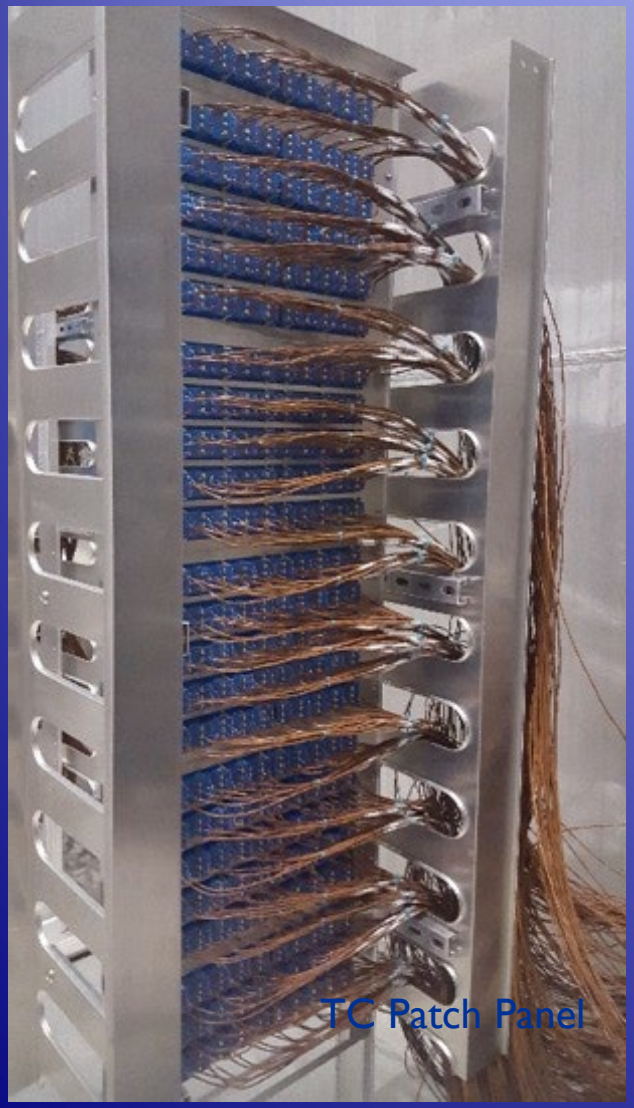
- Chamber Floor 52” penetration plate
  - 22 passthroughs
  - Can accommodate up to 2.5” diameter line
  - Smaller lines can utilize a “bayonet” concept for thermal standoff from penetration plate.
- Feedthroughs on aluminum chamber should be vacuum-rated
- Typical total line lengths: 200+ feet (60+ m) long



Chamber Floor MGSE 52” Penetration Plate
SPF Drawing PE-1411-00044030-M-401



Temperature Measurements


TC Patch Panel

- Facility Data System can accommodate 1280 Type-T thermocouples
  - 120 Facility Type-T thermocouples
  - 1160 locations for customer Type-T thermocouples
- Heat Flux System includes:
  - 112 Type E TCs
  - 184 Type T TCs (40 TCs directly connected to PLC)
  - 16 RTDs
- Thermocouples connect through Thermocouple Patch Panels can accept 2- or 3-pole standard plugs

Full-Scale Spacecraft Test



Orion Program
Artemis 1 Crew Module/Service Module Vehicle
Thermal Vacuum/Thermal Balance

Full-Scale Fairing Deployment Tests



Atlas Fairing



Delta IV - EELV



Atlas V - EELV



Ariane 5 / Atlas V



Sky Lab



Titan



Ariane 5



Centaur

Full-Scale Fairing Deployment Tests



Ariane 5 HSS3 / HSS3+



SpaceX Falcon 9 Vers. 1.1

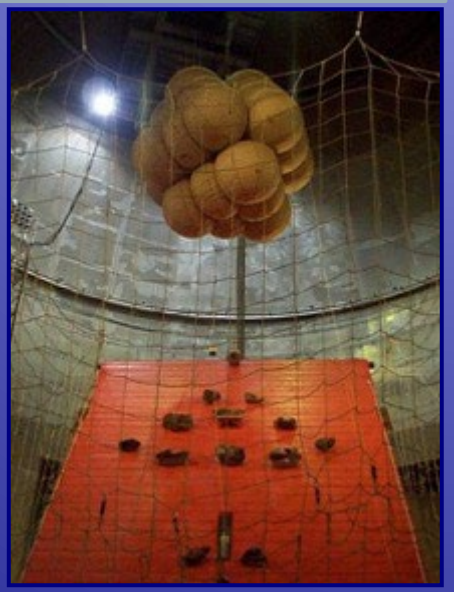


Blue Origin New Glenn

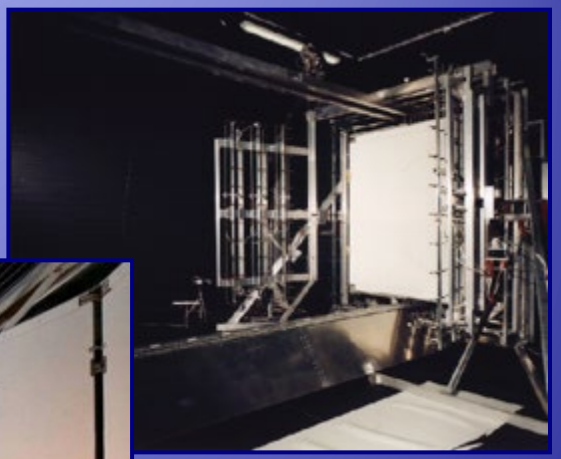
Spacecraft Component Tests







Mars Exploration Rovers
Spirit* and *Opportunity
Airbag Landing System Tests

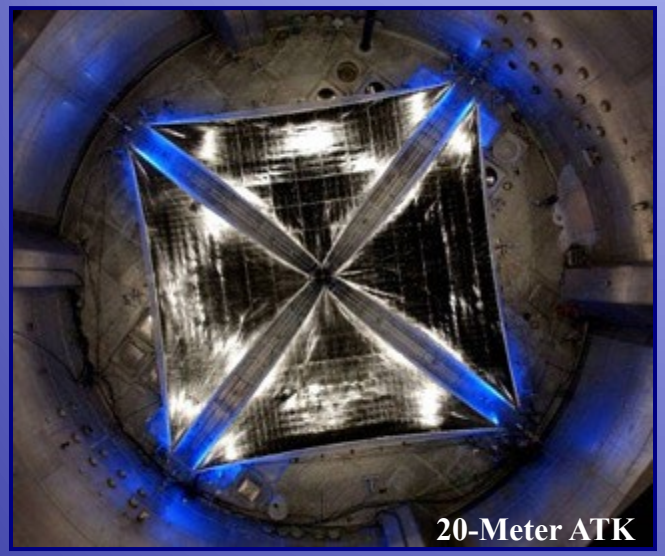






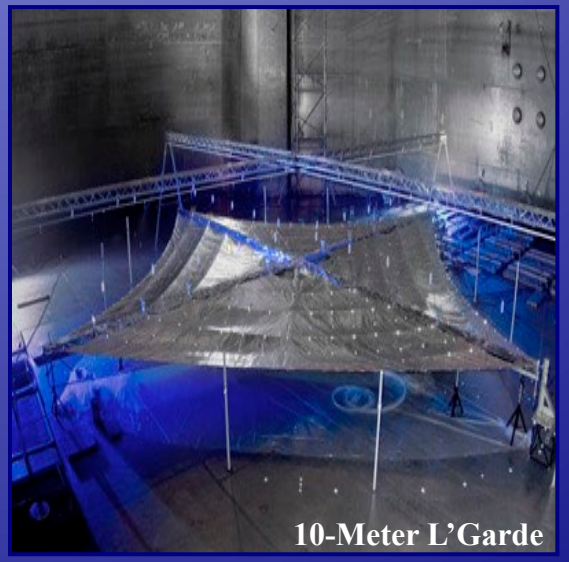
International Space Station
Radiator Deployment and Performance Tests

Solar Sail Tests

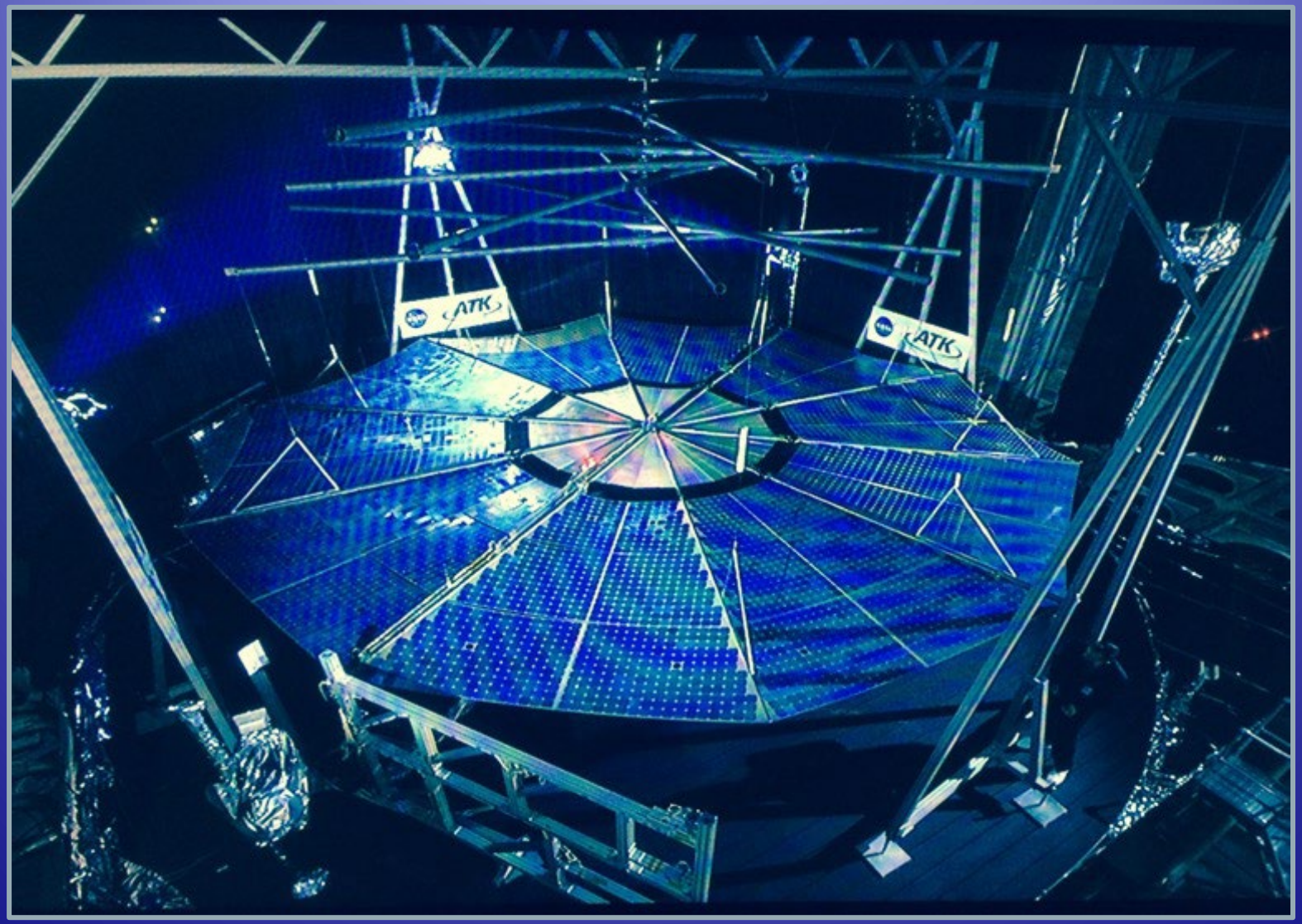

20-Meter ATK


20-Meter ATK


20-Meter ATK


10-Meter L'Garde

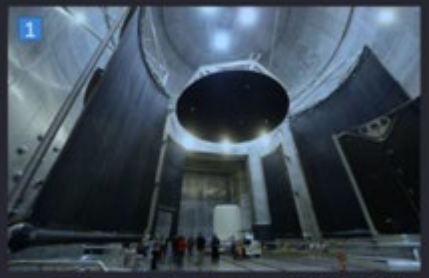
Solar Array Deployment Test



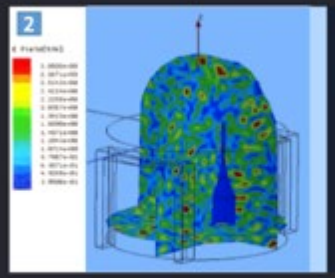
ATK MegaFlex 9.5m Array Deployment

Space Environments Complex EMI/EMC Capabilities

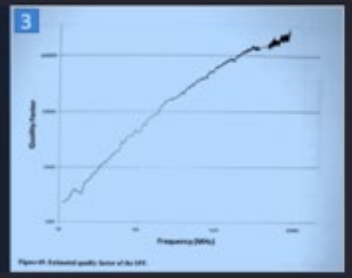
In 2009 the SEC Thermal Vacuum Chamber was characterized by NIST as the world's **largest** and best **electromagnetic reverberant chamber**[1]



SEC is an **electrically large** (120' x 100') and **electrically complex** RF cavity



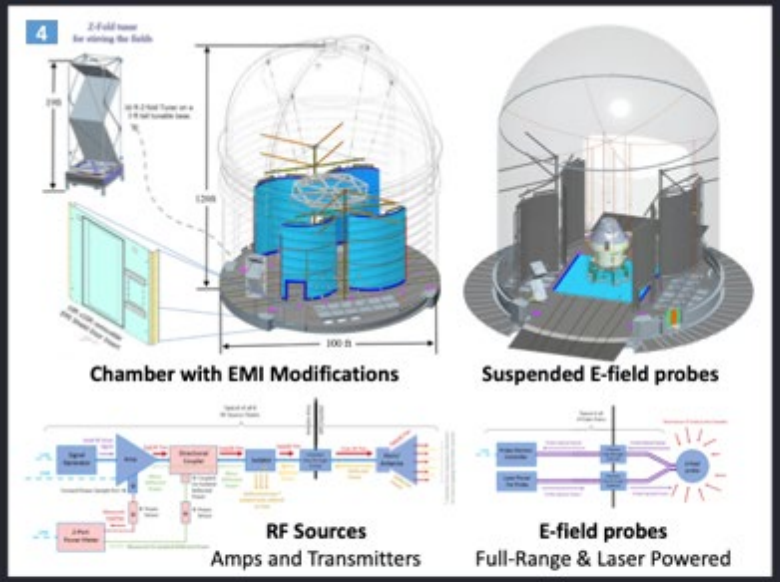
Due to its **size**, SEC has good mode density **as low as 65 MHz**



Due to SEC's **aluminum construction** it has extremely high **"Q" (~1x10⁶)** [2]



Probes and Tuner inside the chamber during Testing

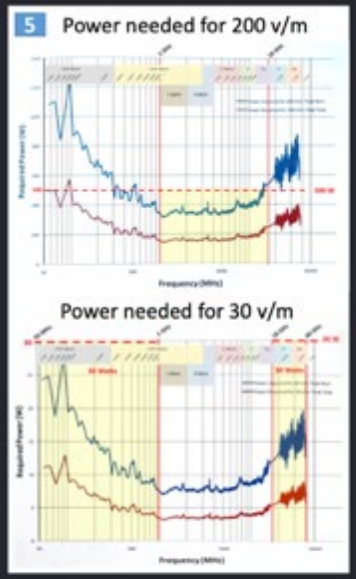


Chamber with EMI Modifications

Suspended E-field probes

RF Sources
Amps and Transmitters

E-field probes
Full-Range & Laser Powered





High-Power amplifiers just outside the chamber



High-Power antennas and horns just inside the chamber

By adding a **19 ft. rotating "Z-Fold" mode-stirrer** and a **custom Shield-Door Insert** to facilitate the use of RF test and measurement equipment, the chamber has been converted to a fully functional and **calibrated** [3] EMI/EMC Reverb chamber with excellent: **Uniformity, Isotropy, and Random Polarization.**

These and other unique properties, combined with additional modifications to the chamber, enable the SEC chamber to provide **electric fields levels** sufficient for **radiated susceptibility and immunity testing** on **full-scale vehicles** using readily available RF amplifiers

https://www1.grc.nasa.gov/facilities/emi/

NASA STI # 55258

Ref: [1] NIST-TN-1558, [2] IBID Pg. 81, [3] NASA/TM-2014-218363

Space Environments Complex
EMI/EMC Capabilities

Benefits of the SEC E3 chamber

- Chamber height provides capability to test large vehicle assemblies
  - Majority of reverberation chambers are room sized
- SEC E3 chamber is reverberant at lower frequency ranges of 50-65 MHz
- Test Articles can be subjected to multiple RF bands in the reverberant environment, reducing testing periods.
- Multiple test capabilities at SEC allow more of a “one stop shop” approach to testing with the availability to perform thermal vacuum, reverberant acoustic, vibration testing along with E3 testing.

Space Environments Complex
EMI/EMC Tests



Orion EM-1 EMI/EMC Testing

Space Environments Complex
- Vibroacoustic Facilities



Mechanical Sine-Vibration Facility



Reverberant Acoustic Test Facility

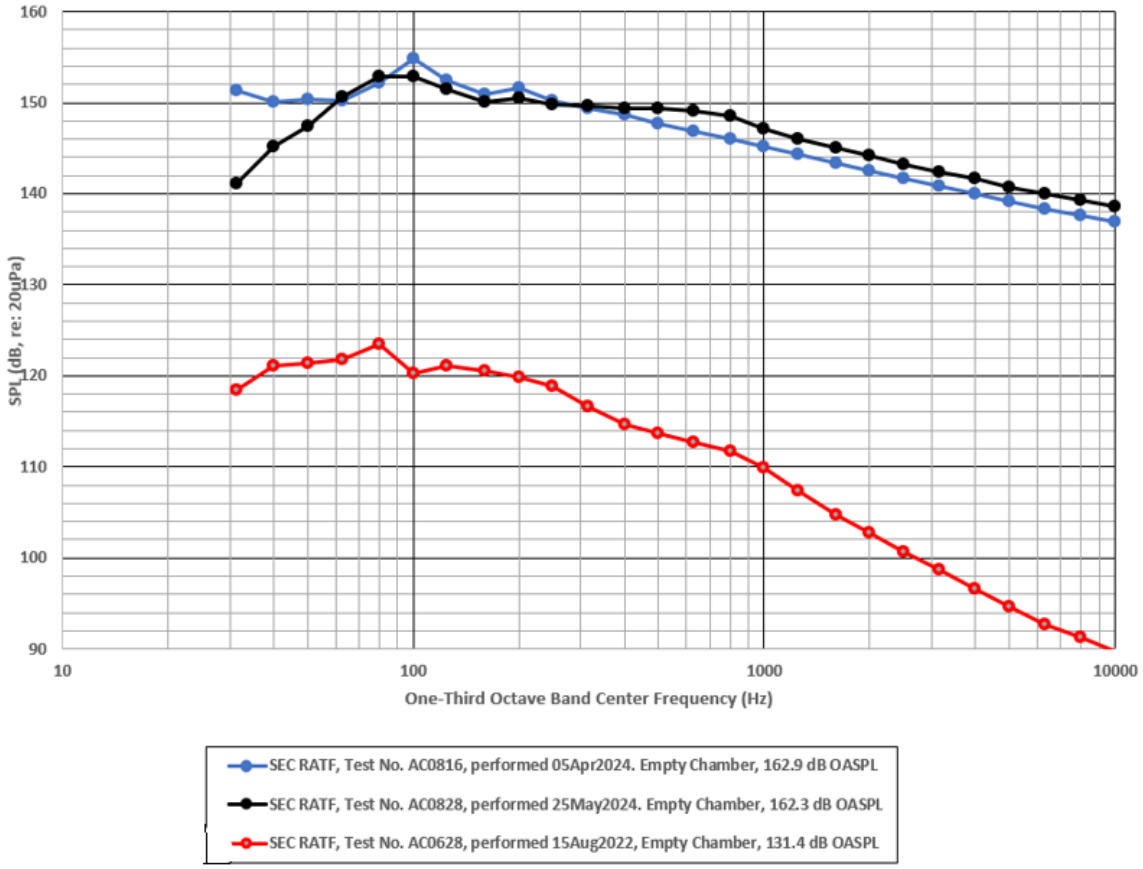
Reverberant Acoustic Test Facility

- Physical Dimensions: 37.5’ W x 47.5’ L x 57’ H, Volume = 101,189 ft3
- Overall Sound Pressure Level 163 dB (empty chamber maximum)
- M+P Acoustic Control System
- LN2 Storage Facilities and Real-Time GN2 Vaporization Provides:
  - **Chamber GN2 pre-purge**
  - **Typical incremental stepwise dB increments (-12 dB, -9 dB, -6 dB, -3 dB, 0dB, and a post -6dB)**
  - **10 minute run time at final 0 dB set-point (assuming all 36 modulators are active)**
  - **70,000 Cubic Feet/Minute nitrogen gas generation to acoustic modulators**
- 36 acoustic modulators (23 servo hydraulic, 13 electro-pneumatic)
  - **12 Team Corp. Mark VI - 150 kW**
  - **11 Team Corp. Mark VII - 175 kW**
  - **13 Wyle WAS5000 – 10kW**
- 4 million acoustic watts in horn room

	Horn Cutoff Frequency						
	25 Hz	35 Hz	50 Hz	80 Hz	100 Hz	160 Hz	250 Hz
Modulator Type	MK VII	MK VII	MK VII	MK VII	MK VI	MK VI	WAS 5000
Qty.	2	2	4	3	4	8	13

Reverberant Acoustic Test Facility

NASA Armstrong Test Facility: RATF Empty Chamber achieved examples showing the range of two Maximum Spectrums and One Minimum Spectrum



One-Third Octave Band Center Frequency (Hz)	SEC RATF, Test No. AC0816, performed 05Apr2024. Empty Chamber, 162.9 dB OASPL	SEC RATF, Test No. AC0828, performed 25May2024. Empty Chamber, 162.3 dB OASPL	SEC RATF, Test No. AC0628, performed 15Aug2022, Empty Chamber, 131.4 dB OASPL
31.5	151.4	141.1	118.4
40	150.1	145.2	121.1
50	150.4	147.4	121.4
63	150.3	150.7	121.9
80	152.2	152.9	123.5
100	154.9	152.9	120.2
125	152.4	151.5	121.1
160	151.0	150.1	120.6
200	151.6	150.4	119.8
250	150.2	149.9	118.9
315	149.4	149.7	116.7
400	148.7	149.4	114.6
500	147.7	149.4	113.6
630	146.9	149.0	112.8
800	146.1	148.6	111.7
1000	145.2	147.1	109.8
1250	144.3	146.1	107.3
1600	143.4	145.1	104.7
2000	142.5	144.2	102.7
2500	141.7	143.3	100.6
3150	140.9	142.4	98.6
4000	140.0	141.6	96.6
5000	139.1	140.8	94.6
6300	138.4	140.0	92.7
8000	137.6	139.3	91.2
10000	136.9	138.6	89.8
OASPL ->	*162.9*	*162.3*	*131.4*

Acoustic Tests Examples



SpaceX 5m Fairing



ATK MegaFlex (Stowed)



Orion Crew Module Back-Shell Panel



Orion LAS Ogive Fairing/Hatch



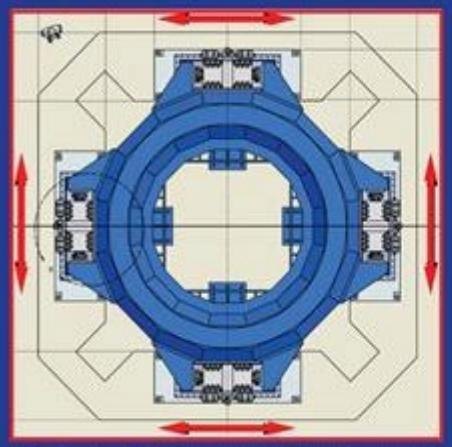
Orion ETA with OGIVES



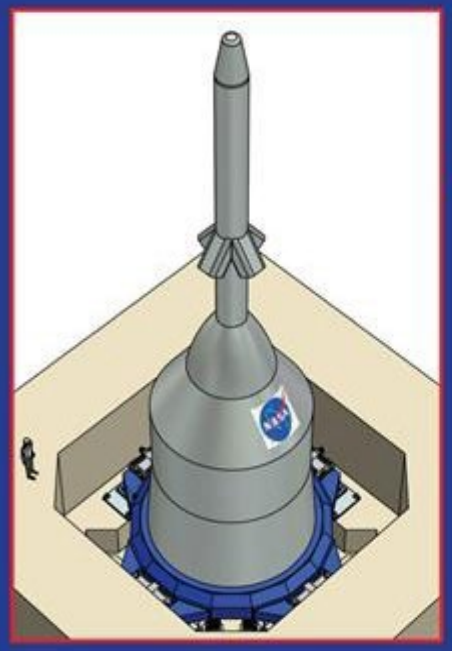
Orion E-STA Service Module

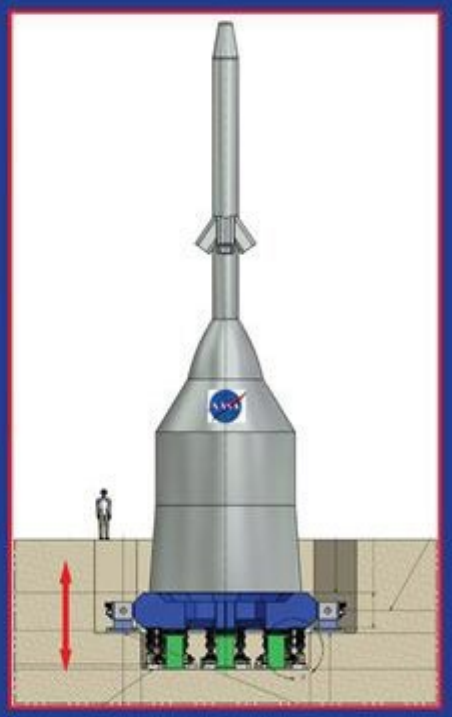
Mechanical Vibration Facility

- **6 degree of freedom, 3-axis servo-hydraulic vibration system**
  - Payload: 75,000 lb @ 23.6' elevation Cg
    - 50,000 lb @ 23.6' elevation Cg with table expander
  - 2 -150 Hz.; 1.25 g's vertical
  - 2 -150 Hz.; 1.0 g's horizontal
- **Change vibration axis without removing test article**
- **Data Physics 64-channel closed-loop vibration control system. 31 channels available to customer for response-limiting**
- **Analog abort system**
  - 64-channel National Instruments CompactRIO
  - 23 Trig Tek Model 530A tracking filters on MVF control channels
- **4.5 million pound reaction mass**
- **Modal plate anchored to reaction mass**
- **Headroom of 67' under crane bridge**



2-Axis Orthogonal Horizontal





Vertical Axis

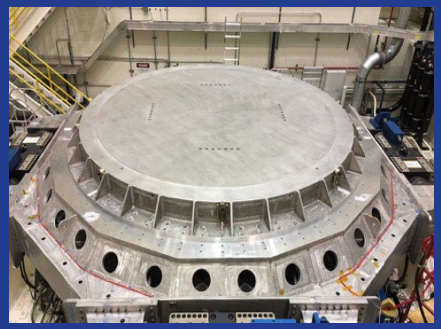
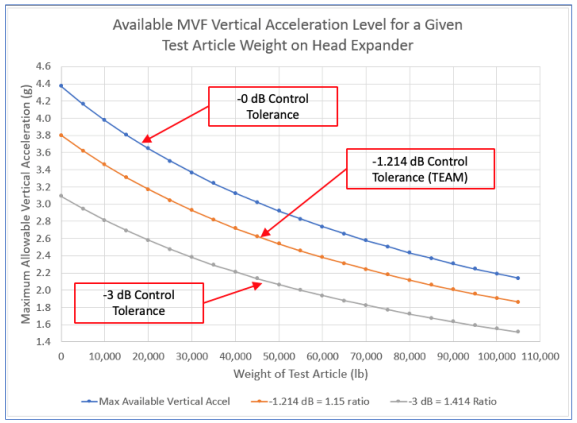


Table Expander

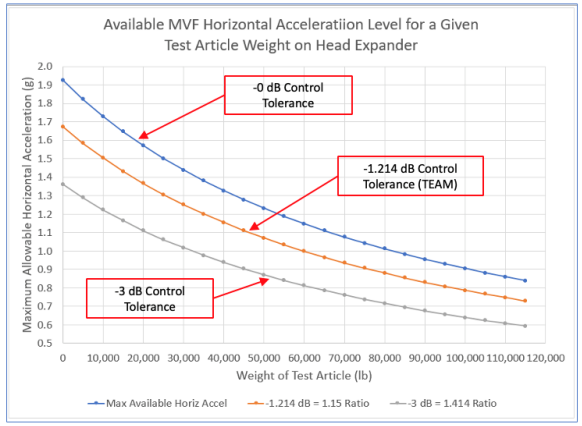
Mechanical Vibration Facility

NASA Armstrong Test Facility: MVF Allowable Vertical and Horizontal Acceleration Given Test Article Weight with the SEC Table Expander Installed

Maximum Allowable Vertical Acceleration for a Given Test Article Weight on the MVF System with Head Expander

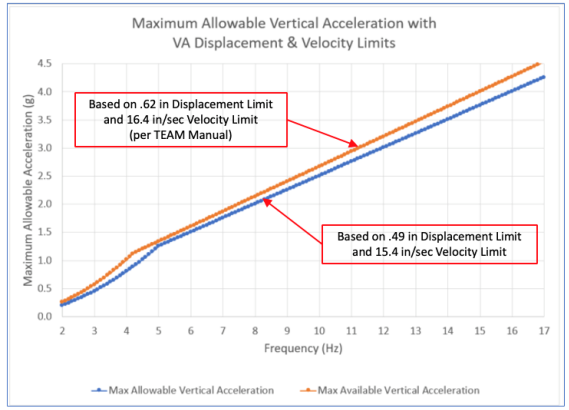


Maximum Allowable Horizontal Acceleration for a Given Test Article Weight on the MVF System with Head Expander

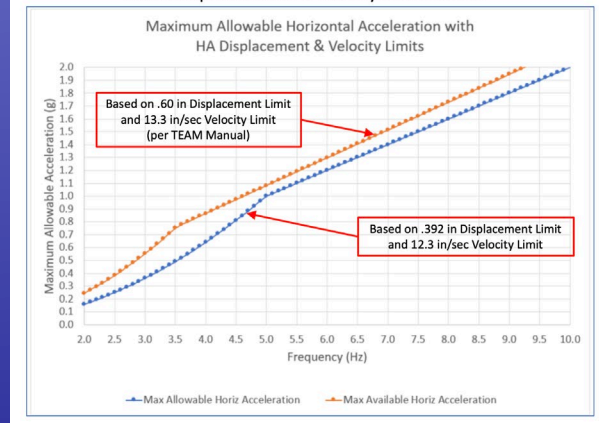


NASA Armstrong Test Facility: MVF Allowable Vertical and Horizontal Acceleration at Lower Frequencies due to Displacement and Velocity Limits on actuators.

Maximum Allowable Vertical Acceleration at Lower Frequencies Due to Displacement and Velocity Limits on VA's



Maximum Allowable Horizontal Acceleration at Lower Frequencies Due to Displacement and Velocity Limits on HA's



Vibration Tests

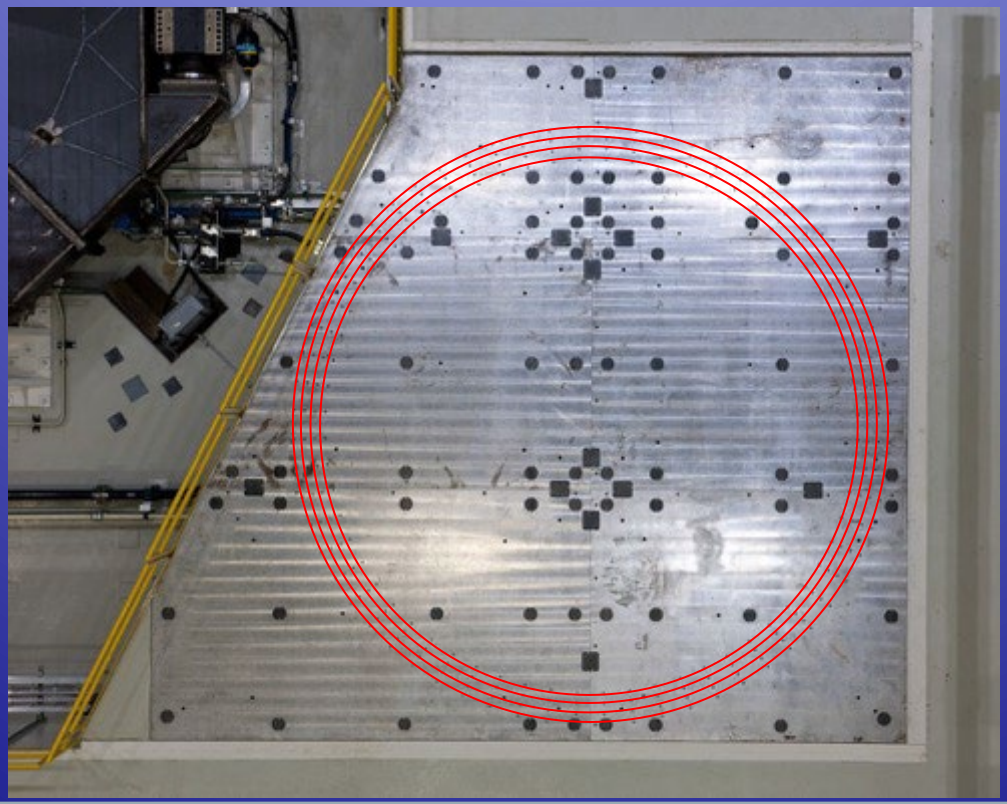
- Orion European Space Agency Service Module Structural Test Article (E-STA)
- Sierra Space Dream Chaser
- Space X Falcon Heavy payload adaptor fitting





Modal Facility

- MVF seismic mass includes a 'Modal Plate'. A 6" steel slab with >11E^6 lb/in stiffness mounted to the 4.5 million pound seismic mass
- Several fixed-base modal tests have been performed on the plate
- Threaded holes match MVF table mounting pattern



Vibroacoustic Data Acquisition Capabilities

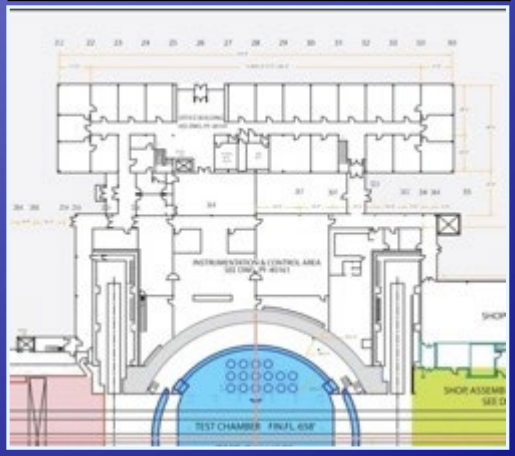
- **Facility Data Acquisition System (FDAS) [Vibroacoustic High-Speed Acquisition]**
  - Channel Count: 1024 channels, ± 10 Volt
  - Sample Rates: 50,000 samples/sec all channels
  - Measurement Band-width: DC to 20 kHz, alias-free (DC to 111 kHz limited channels)
- **Mobile Data Acquisition System (MDAS) [Thermal Vacuum & Mobile Data Acquisition]**
  - Channel Count: 256 channels, ± 10 Volt
  - Sample Rates: 256,000 samples/sec (all channels)
  - Measurement Band-width: DC to 111 kHz, alias-free
- **Common Architecture:**
  - IRIG-B synchronized common clock
  - Real-time monitoring and playback (PSD, Octave-band display, Time-series display, etc.)
  - Data Outputs: 1) UFF58
  - Signal Conditioning: (Precision Filters 28000 Series)
    - 768 IEPE type channels (50, 16-channel cards). Accelerometers, microphones. TEDS compatible. (Precision Filters 28316C)
    - 184 quad-channel constant-voltage or constant-current conditioners. Supports strain gauges, pressure transducers, RTD's, or other resistive transducers. (Precision Filters 28104A or 28144-LP4FP-L)
    - 40 channels (in groups of 4), IEPE or Charge-Type (selectable) channels. (Precision Filters 28304-HP4F)

Facility Support Systems

- 6,000 GPM cooling tower water
- Two 70,000 SCF GN2 roadable trailer stations
- Service/instrument air system - 95 psig
- Dual-redundant electrical substation
  - 14 MW total
  - 7 MW available for Vacuum Chamber
- Facility-wide intercom/paging system
- Office Building (16,000 sq. ft.) w/46 offices
- Thermal-Vacuum Control Room (900 sq. ft.)
- Vibroacoustic Control Room (1800 sq. ft.)
- Control Room Auxiliary Space (1450 sq. ft.)
- Locker Room (1300 sq. ft.)
- ISO 7.0 Soft-walled Portable Cleanroom (80 sq. ft)







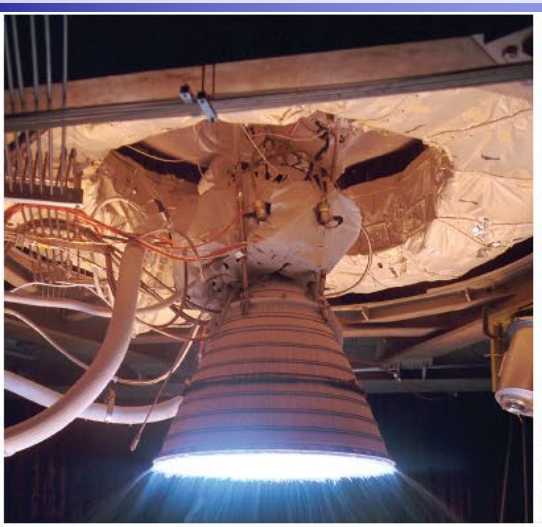
Contamination/FOD/Environment

- Assembly highbay/High Vacuum Chambers - Classified ISO 8.5 facility (ISO 8.0 capable)
- FOD/contamination facility in plan to control debris-creation and migration
- 4 Airborne Particle Counters located to monitor particles in active areas
- Highbays condition air:
  - Temperature: 65-77 F
  - Humidity: 30-60 %RH
- Vacuum chamber has no active means to condition air – relies on highbays system to circulate air



Assembly Highbay HVAC Filters						
HVAC Unit	Purpose	Capacity	Pre-Filter	Filter	Final Filter 1	Final Filter 2
MAU-69	Make-up Air	12,000 CFM	Pleated MERV 8	MERV 13	N/A	N/A
AH-69N	Conditioning	30,000 CFM	Pleated MERV 8	MERV 13	N/A	N/A
AH-69S	Conditioning	30,000 CFM	Pleated MERV 8	MERV 13	MERV 7	MERV 8

NASA Neil A. Armstrong Test Facility
In-Space Propulsion (ISP) Facility



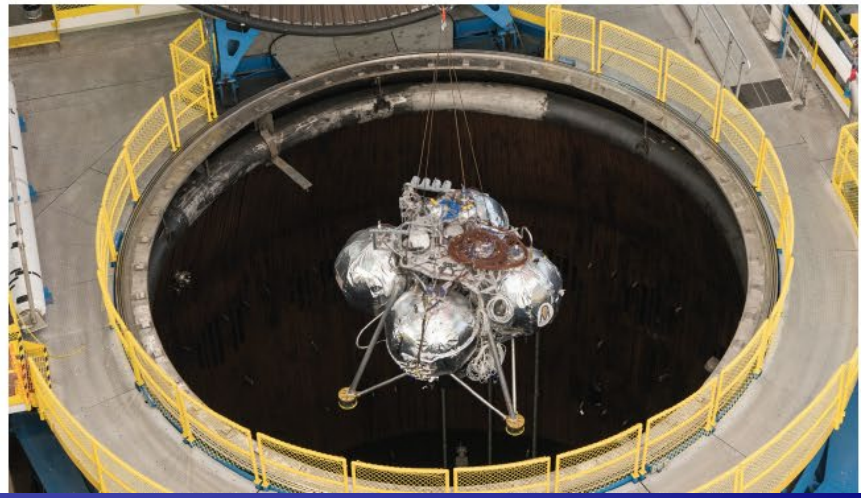
The world's largest space simulations facility capable of full-scale rocket engine and stage testing.



The largest hydrogen-compatible thermal vacuum test facility in the United States.







ISP Facility Unique Key Features

- ***World's largest (and NASA's only large) thermal vacuum propulsion test facility***
  - Engines up to 125K lb thrust
    - Up to 400K lb thrust with facility mods
  - Allows "full-scale" vacuum testing of liquid fueled rocket engines and entire stages
  - Capable of long duration cold-soak and solar heating simulation
    - Critical for on-orbit or interplanetary engine restart testing
  - Capable of engine "hot-fire" at 0.15 psia (100K ft altitude)

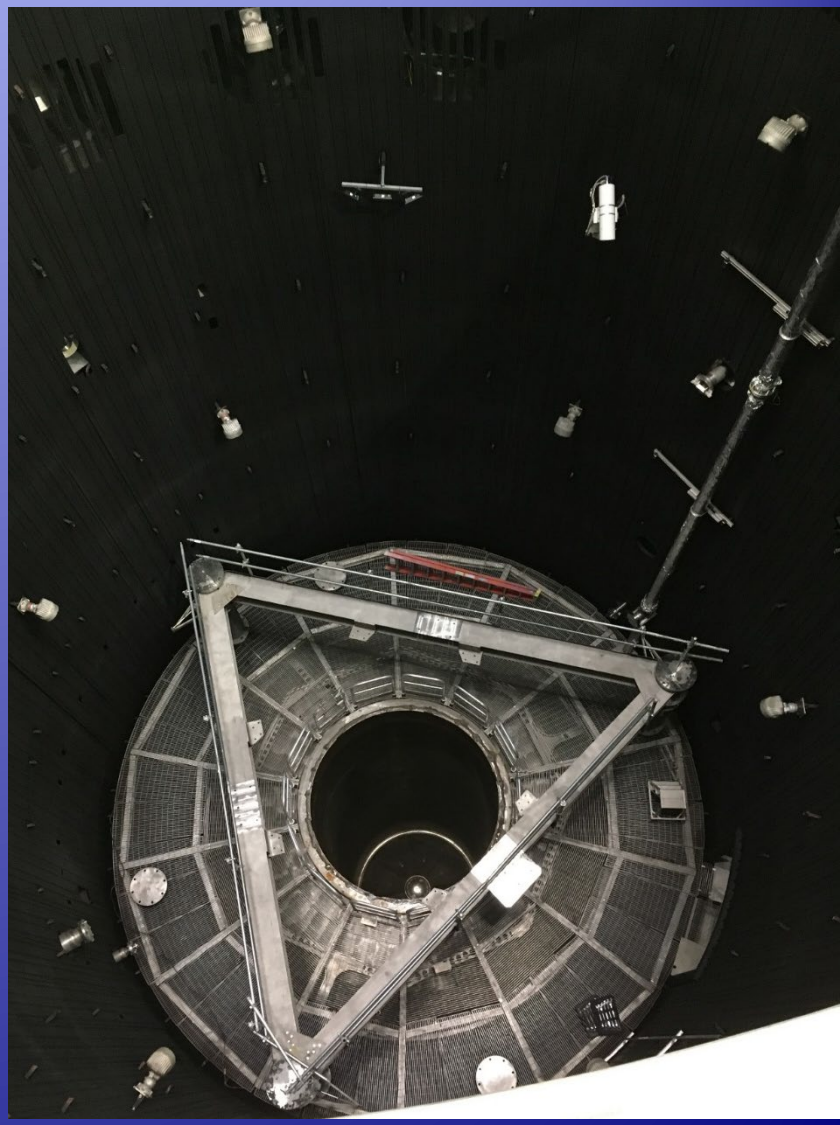
- ***World's largest thermal vacuum chamber capable of testing with hazardous propellants***
  - Entire facility is rated Class 1, Div II, Group B for hydrogen/oxygen testing
  - Facility has a very large exclusion zone (buffer area) around it

Neil A. Armstrong Test Facility
In-Space Propulsion (ISP) Facility Campus



ISP Facility Baseline Subsystems

- **Test Chamber**
  - Dimensions: 38 ft diameter / 65 ft tall
  - Copper fin and tube LN2 heat sink maintains temperature at -320°F (77K)
  - Thermal lamp array rotisserie heating (600 kW total) / heater panels
- **Diffuser**
  - Dimensions: 11 ft diameter / 37 ft tall
  - Backside water cooled



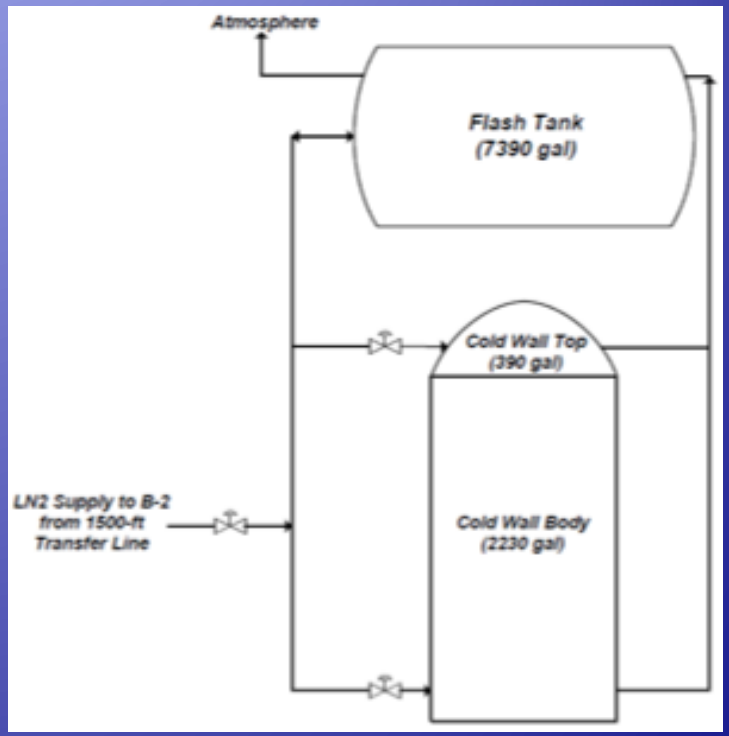
ISP Facility Baseline Subsystems

- **Vacuum**
- Ultimate vacuum
  - 2 x 10^{-5} Torr w/o heat sink
  - 5 x 10^{-6} Torr with heat sink
- Evacuation time to best vacuum is approximately 24 hours, depending on test variables.
- 4 torr takes 2.5 hrs
- Break vacuum for chamber entry can take up to 24 hrs
- Vacuum achieved with mechanical and oil diffusion pumps.



ISP Facility Baseline Subsystems

- **Cold Wall Heat Sink**
- Baseline cold thermal condition provided a liquid nitrogen cold wall consisting of copper tube-in-strip panels surrounding the inside wall (2230 gallons) and top cap (390 gallons) of the test chamber
- Bottom surface of test chamber not fitted with cryopanels
- Provides a nominal -320 deg F (77K) radiative environment inside the chamber when full.
- Cold wall liquid level maintained by gravity feed from a flash tank located above the chamber
- Replenishment of the flash tank from exterior LN2 supply keeps the cold wall flooded throughout testing. Can be maintained indefinitely for continuous long duration testing.



ISP Facility Baseline Subsystems

- **Spray Chamber**
  - Dimensions: 67 ft diameter / 120 ft tall
  - Water Capacity at 65 ft depth: 1.7 million gallons
  - Four 2,000 HP recirculation pumps provide 225,000 gallons per minute to spray bars to cool rocket exhaust
  - Three 1,000 HP pumps provide 40,000 gallons per minute to steam ejectors to condense exhaust steam



ISP Facility Baseline Subsystems

Main Steam Ejectors

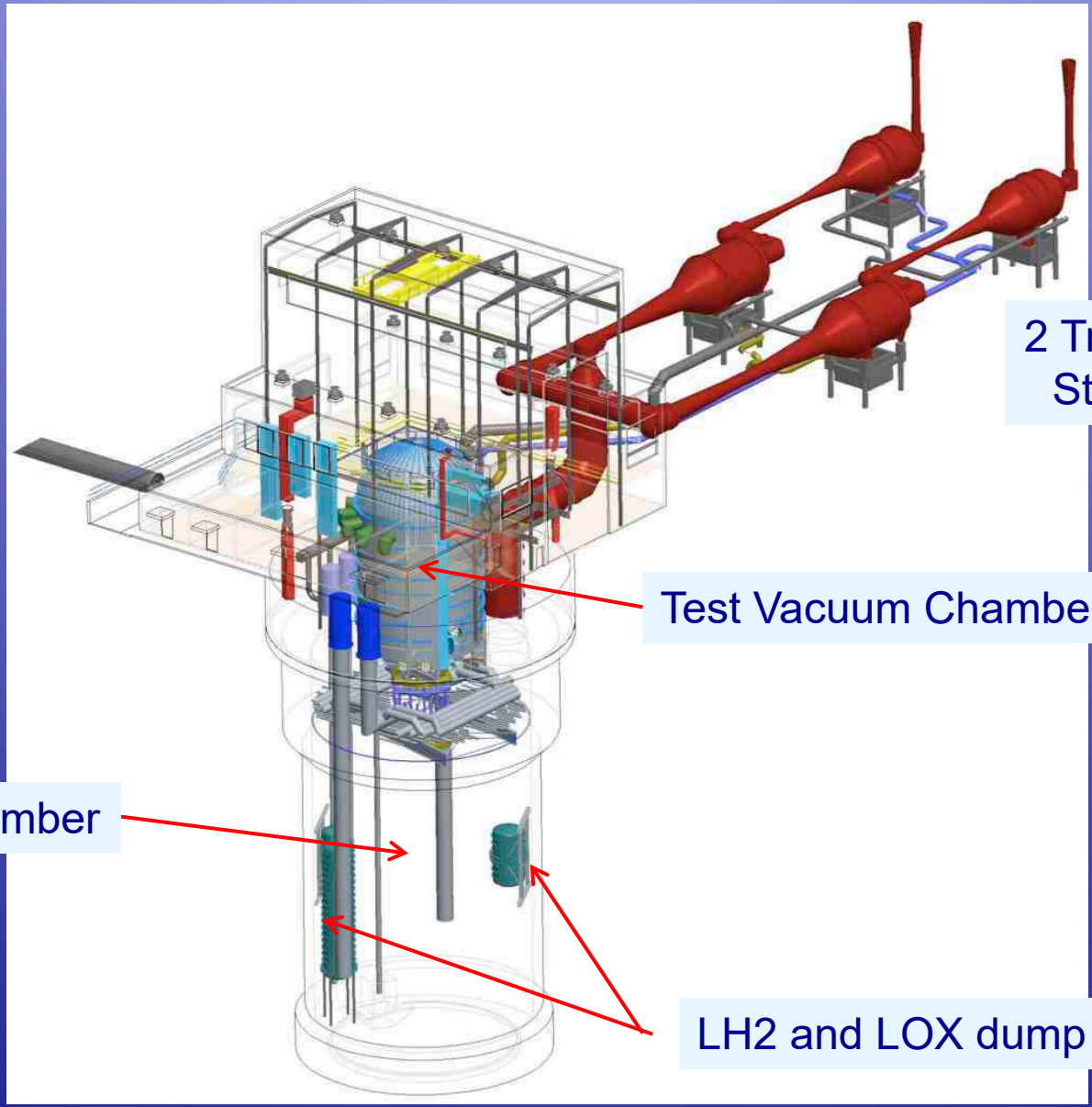
- Two train three stage steam ejectors
- Intercondensers cool steam
- Consume 180 pps steam per train



Auxiliary Steam Ejectors

- Two train three stage steam ejectors
- No intercondensers
- Consume 5 pps steam per train




2 Trains, 3 Stages
Steam Ejectors
Test Vacuum Chamber
Spray Chamber
LH2 and LOX dump tanks

Thermal Simulation

- 550 kW total power capacity
- 32 Individually controlled zones each capable of 15 kW
- 26 Heater panels 52” x 144” on test chamber wall (15 kW capacity)
- Custom heater panel shapes and configurations can be fabricated.
- Infrared lamps also available





Modernized Controls System

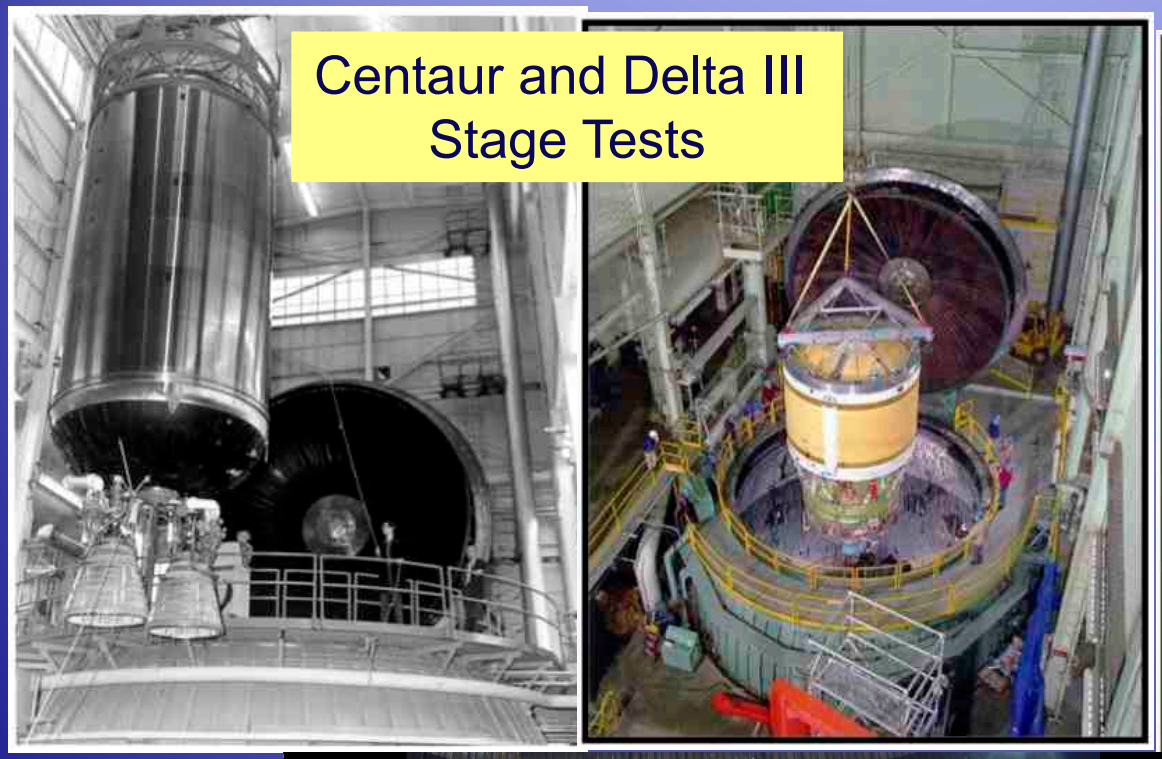
- State of the Art Controls System – PLC Based
  - Dual core processors enhance speed and scan time to support redundant PLC operation.
  - Redundant network cable on Ethernet, Fiber, and RIO Cabling.
  - Distributed architecture with Remote Input & Output (RIO) drops throughout the facility.
- State of the Art Data Acquisition System
  - 512 Low Speed channels, 32 High Speed Channels
  - 288 channels of digital TC's
  - Precision Filters Signal Conditioners integrated into DAS controls



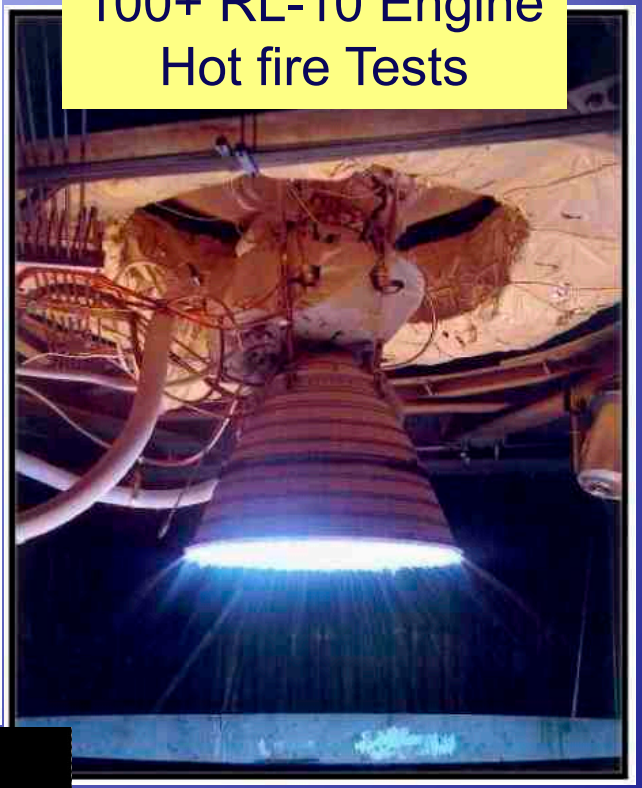


Rich History of Propulsion Testing

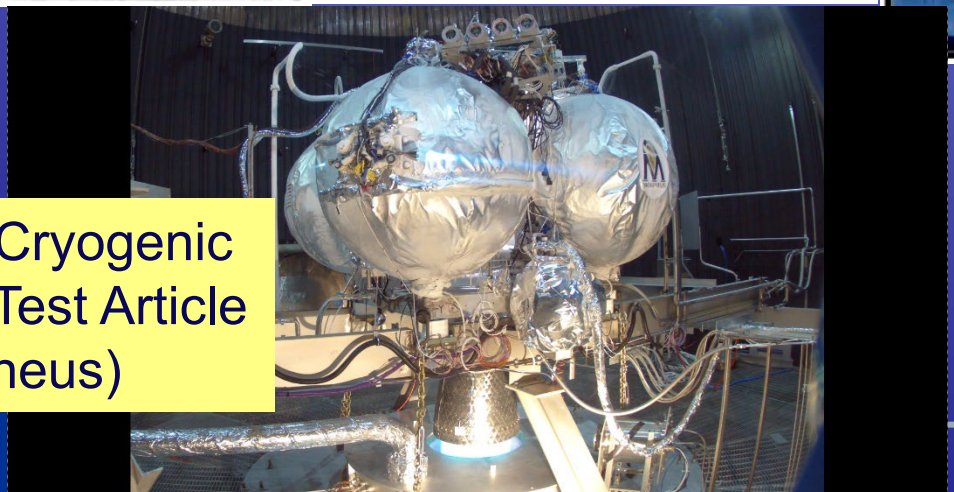
Centaur and Delta III Stage Tests



100+ RL-10 Engine Hot fire Tests



Integrated Cryogenic Propulsion Test Article (Morpheus)



Pulse Detonation Research Engine



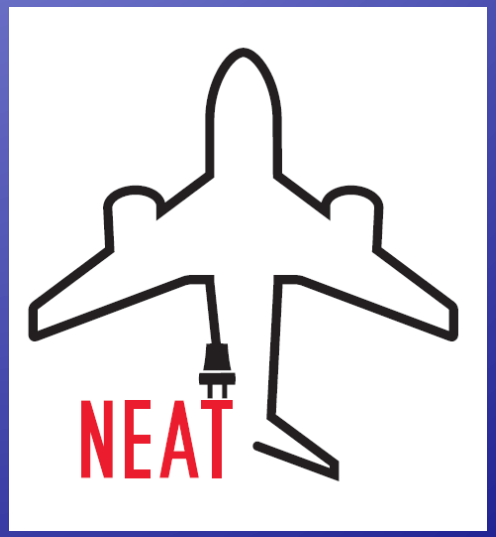
NASA Electric Aircraft Testbed (NEAT)



NEAT Overview

- Designed to enable end-to-end development and testing of the electric portion of MW-scale electrified aircraft powertrain systems

- Designed with a reconfigurable architecture that industry, academia, and Government can utilize to further mature electrified aircraft technologies.



NEAT Test Areas

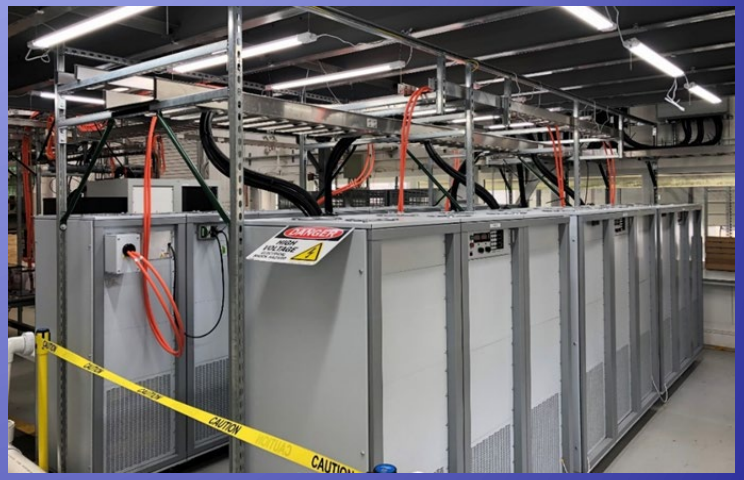
- Main Test Area
  - Large enough for 737-class electric powertrain (sea level testing)
- Test Chamber
  - Chamber dimensions of 33ft diameter major axis, 28ft diameter minor axis, 18ft ceiling
  - Reinforced concrete floor
  - Pumps currently capable of operating at 60,000 ft (15 minute pump down)





NEAT Electrical Power

- External Power source12 MVA available at 4160 VAC
- 3 MVA of 3-phase, 480VAC transformed to date for testbed use
- Further transformer upgrades made when additional power is required, up to the full 12 MVA
- Total of 4 MW DC power 16 Magna units
  - Each unit is 250 kW, 0-700 VDC, 0-357 A
  - Power supplies can be reconfigured in series and parallel to reach higher voltage levels
- 550kw of bidirectional DC power
  - 2 Arbin Units
  - Each is 275 kW, 0-700V DC, 0-392 A



Magna Power Supplies

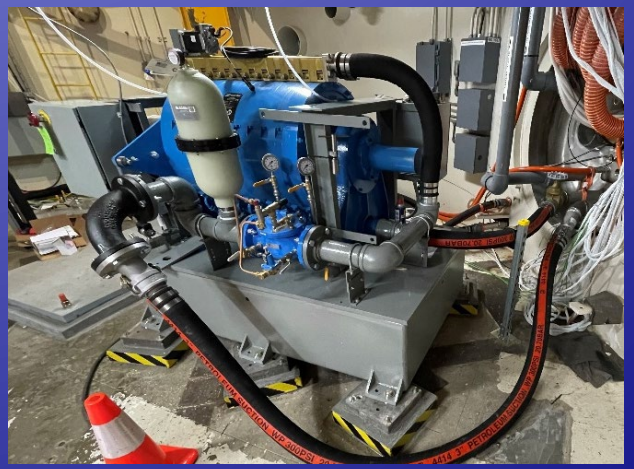


NEAT Electric Machine Testing

- Commercial off-the-shelf machines and drives can be configured as dynamometer
  - Two dual-250 kW Parker Motors can be connected to one shaft for 1 MW of shaft power for motor and generator testing at 7000rpm
- Dedicated 3.3 MW Water Brake dynamometer for motor testing
- Gearbox Units
  - Have (2) 1 MW gearboxes to accommodate different operating speeds for powertrain components. 3:1 ratio expands speed profile up to 21,000rpm
  - 5.0 MW gearbox to operate with Water Brake Dyno



Unshrouded Electric Dyno



Water Brake Dyno

NEAT Cooling

- Primary Cooling System – Propylene Glycol/Water 1MW
- Additional Liquid Cooling – Polyalphaolefin (PAO) Chiller
  - 50kW
  - System designed to provide up to 50 gpm at 176ºF
- Instrument Air
  - 240 CFM @ 100 PSIG
  - Can provide air to the gearbox and test article



PAO Chiller

NEAT Data Capabilities

- High-speed data (10Hz – 200kHz):
  - 64 analog inputs (voltage, current, accelerometer)
  - 64 frequency inputs
  - 16 CAN-bus IO channels
- Low-speed data (0.1Hz – 1Hz):
  - 104 temperature inputs, 176 analog inputs, 16 analog outputs
  - 176 discrete inputs (mixed 24 VDC and 120 VAC),
  - 96 discrete outputs (mixed 24 VDC and 120 VAC)
- Automated Diagnostics of Rotating Equipment (ADRE):
  - 4 key-phasors, 16 orthogonal proximity sensors, 4 accelerometers
  - System is expandable to include health monitoring measurements for dynamometer, gearboxes, and test article