NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

ENVIRONMENTAL TEST AND INTEGRATION FACILITIES HANDBOOK

https://etd.gsfc.nasa.gov/capabilities/capabilities-listing/integration-and-testing/



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD 20771

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Introduction

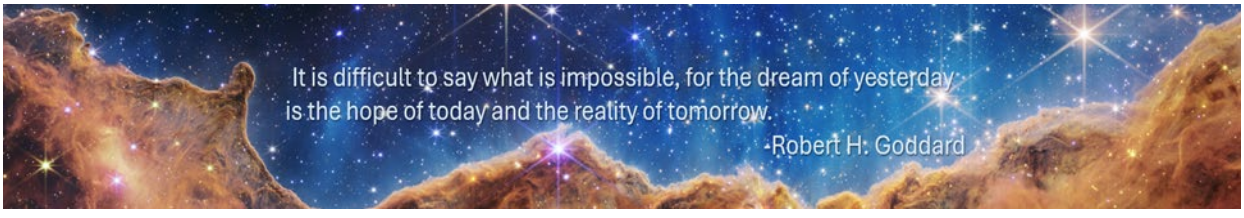
NASA's Goddard Space Flight Center (GSFC) is home to the nation's largest organization of scientists, engineers, and technologists that build spacecraft and instruments to study the earth, sun, solar system, and universe. Scientific missions are carried out from concept, through-design, manufacture, test, launch and operations. To support its science missions, Goddard is committed to maintaining and upgrading its core infrastructure, laboratory facilities and equipment to preserve the Center's preeminence as a national resource and Center of Excellence. The capabilities provided in Goddard's Integration and Test Complex are a key element to realizing its scientific goals.

Goddard's Integration and Test (I&T) facilities are managed by the Engineering and Technology Directorate's Mechanical Systems Division. Goddard's I&T facilities provide projects with cleanrooms and test facilities for building flight hardware and ensuring it will withstand the launch, space, and electromagnetic environments. The Environmental Test Engineering and Integration Branch has long-range goals of advancing state-of-the-art of environmental testing and aiding the development of improved spaceflight systems. Goddard's Integration and Test Complex is one of the most comprehensive and capable spaceflight test facilities within the United States Government.

This handbook provides a comprehensive catalog of Goddard's I&T facilities and their capabilities. These facilities are in Buildings 7, 10, 15 and 29 as shown on the GSFC map found on the next page.

Additional information about Goddard's I&T facilities can be obtained from:

Environmental Test Engineering & Integration Branch
Code 549
Goddard Space Flight Center
Greenbelt, Maryland 20771
(301) 286-2187 or (301) 286-8747



GSFC Map

Goddard Space Flight Center is located at 8800 Greenbelt Road, Greenbelt, MD 20771.

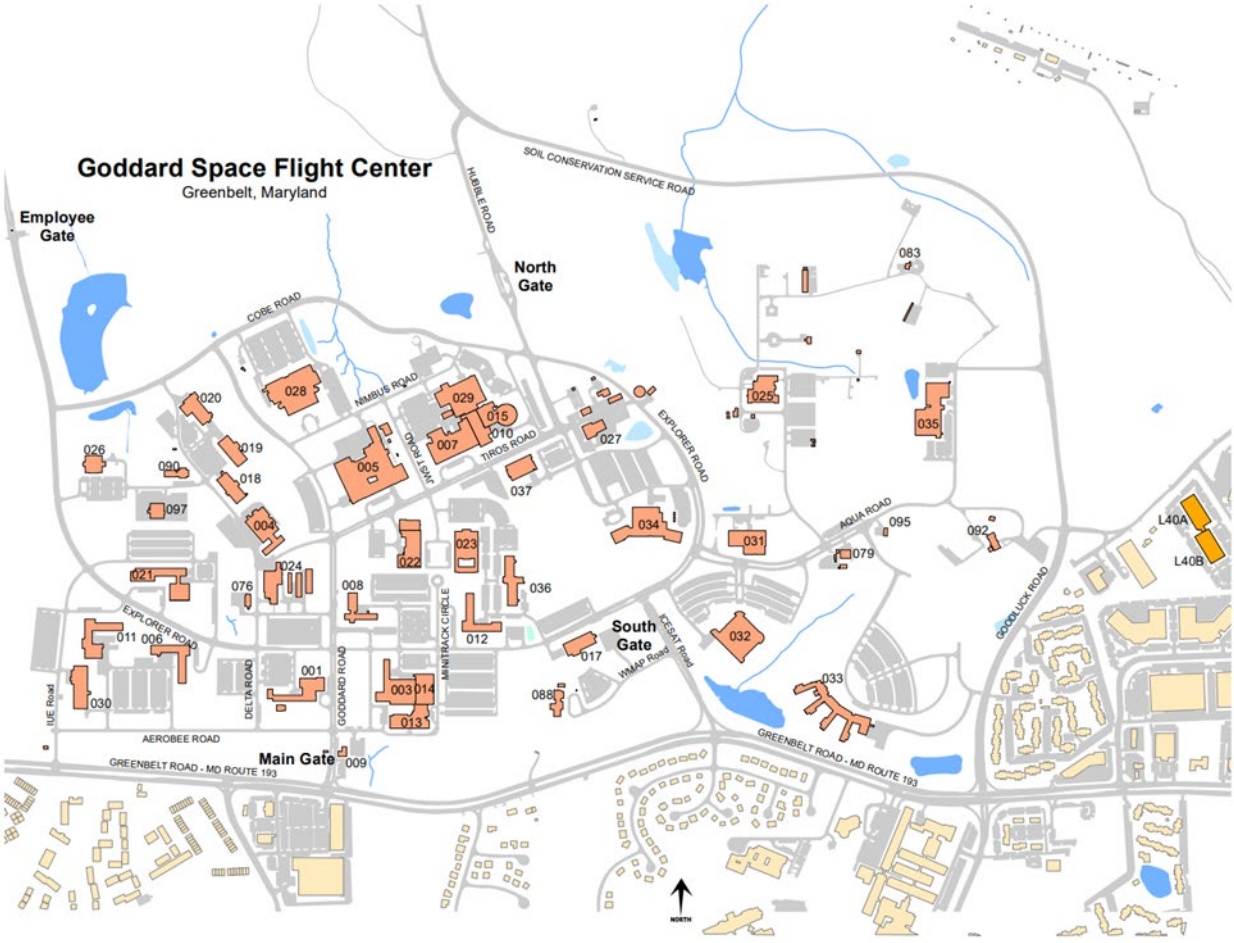


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1.0 ENVIRONMENTAL TEST ENGINEERING SERVICES AND FACILITIES

The Environmental Test Engineering and Integration Branch provides test facilities, instrumentation support, data analysis and experienced staff to perform structural dynamic, electromagnetic and space simulation testing of spaceflight hardware in an effective and safe manner. A full spectrum of test articles, including components, instruments and spacecraft can be thoroughly tested to survive the launch, electromagnetic and space environments. Testing capabilities the Environmental Test Engineering and Integration Branch provide include:

Structural Dynamics:	Acceleration Acoustic Mass Properties and Spin Balance Modal Survey Static Load Vibration / Shock
Electromagnetics:	Electromagnetic Compatibility Electromagnetic Interference Magnetics
Space Simulation:	Bakeout (Outgassing) Thermal Thermal Balance Thermal Vacuum

Details of these environmental test facilities are described in the following sections.

1.1 STRUCTURAL DYNAMIC TESTING

1.1.1 Vibration Facility

General: The Vibration Laboratory provides all necessary services and equipment to perform shock and vibration testing of spacecraft and subsystems. Digital control systems provide sinusoidal, random, and transient waveform control to four separate electro-dynamic exciters. All exciters are rigidly mounted to very large reaction masses that are isolated from the building. Digital data acquisition systems condition and record accelerometer, force, and strain gage signals. A small machine shop with drill press, milling machine, and band saw is available for simple fixture fabrication.

Control System: Two control rooms equipped with a state-of-the-art m+p Vibration Controllers provide excitation signals to the exciters. The controllers can generate sine, random and various transient waveforms (sine burst, classical shock, and SRS shock). The controllers have m+p Vibrunner front ends that are typically configured with 40 channels each. The controllers are capable of digitally recording the time domain signals. The control rooms are also equipped with over test protection systems and response instrumentation conditioning equipment.

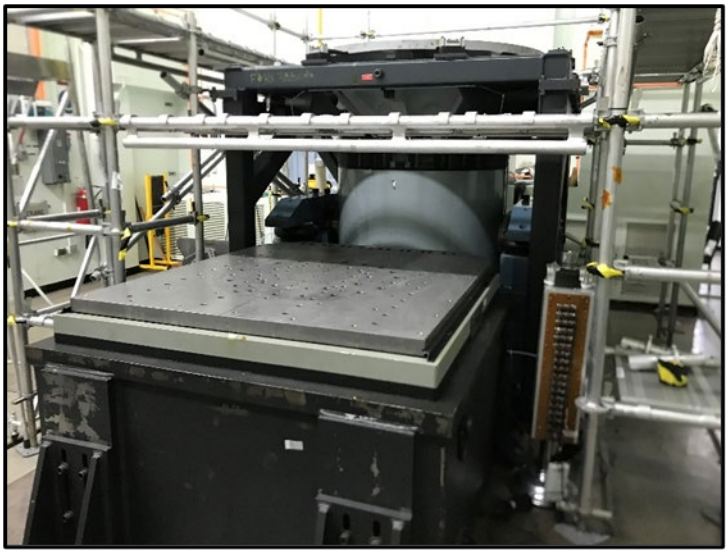
Data Acquisition: For 40 channels or less, data acquisition is provided by the m+p controllers. For larger channel counts, up to 256, data acquisition rates up to 50 ksamples/sec are achievable. An extensive quantity of accelerometers from Kistler, PCB, Dytran, and Endevco are available for your instrumentation needs. Tri-axial force transducers from Kistler are available for force-limited vibration testing. In the event strain data is needed, a 32-channel strain gage conditioning system is available. Personnel trained by Vishay/Micro-Measurements are available for any strain gage installations.

Shaker Supplementary Equipment:

Baughn 60” Dia. Head Expander	
Adapts to:	T4000 shakers (Facility 409 and 410)
Mass:	895lb.
Additional Static Load Support:	12800lbs. at 100psi, 10000lbs. at 80psi
Additional Overturning Moment Capability:	75-80k in-lbs. at armature interface
TRMM 88” Dia. Head Expander	
Adapts to:	Baughn 60” Dia. Head Expander
Mass:	1985lb.
Baughn 24” x 24” Head Expander	
Adapts to:	T2000 shakers (Facility 411 and 412)
Baughn 12” Cube	
Adapts to:	T2000 shakers (Facility 411 and 412)
Mass:	90lb

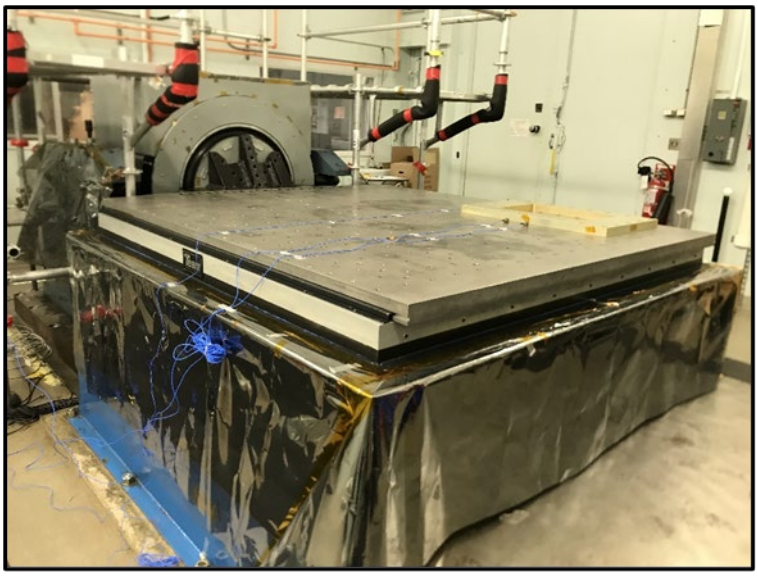
Vibration Exciters:

Facility 409 – Unholtz-Dickie T4000-2 Shaker (with 60" head expander installed)



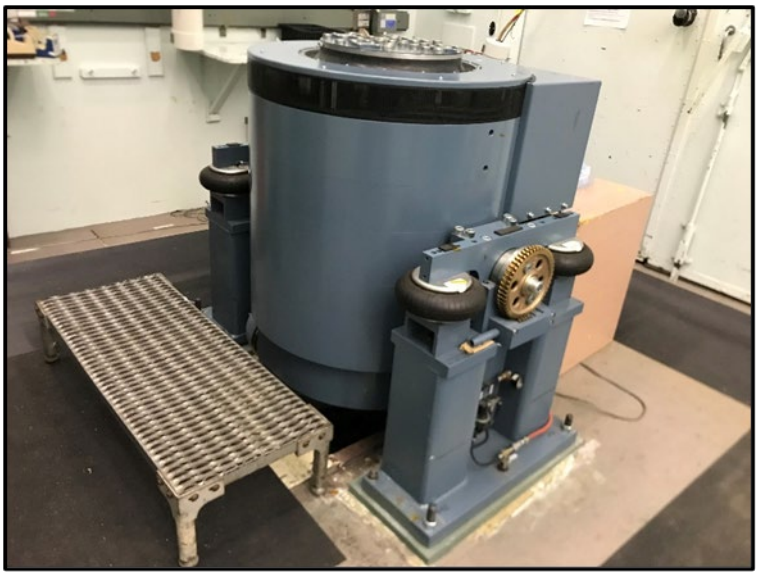
Usable Frequency Range	5 – 2500 Hz
Amplifier Model	2XSAI180 (360 kVA)
Maximum Force (Sine)	40,000 lbf (178kN) pk
Maximum Force (Random)	40,000 lbf (178kN) rms
Maximum Displacement (Continuous duty)	1.8" pk-pk
Maximum Displacement (Intermittent duty)	2.0" pk-pk
Maximum Velocity (Sine)	85 in/s (2.1 m/s)
Maximum Velocity (Shock)	165 in/s (4.2 m/s)
Maximum Acceleration	120 G's
Shaker Internal Load Support	4,000 lb (1,818 kg)
Armature Mass	250 lb (113.398 kg)
Slip Table	Team T-Film
Slip Table Moving Mass	662 lb (300.278 kg)
Dimensions	50" x 50"
Pitch Moment Capacity	3.7×10^6 in-lb (418 kN-m)
Roll Moment Capacity	3.7×10^6 in-lb (418 kN-m)
Yaw Moment Capacity	1.62×10^5 in-lb (18 kN-m)

Facility 410 – Unholtz-Dickie T4000-3 Shaker



Usable Frequency Range	2 – 2500 Hz
Amplifier Model	2XSAI180 (360 kVA)
Maximum Force (Sine)	40,000 lbf (178kN) pk
Maximum Force (Random)	40,000 lbf (178kN) rms
Maximum Displacement (Continuous duty)	2.7" pk-pk
Maximum Displacement (Intermittent duty)	3.0" pk-pk
Maximum Velocity (Sine)	85 in/s (2.1 m/s)
Maximum Velocity (Shock)	165 in/s (4.2 m/s)
Maximum Acceleration	120 G's
Shaker Internal Load Support	4,000 lb (1,818 kg)
Armature Mass	285 lb (129.274 kg)
Slip Table	Team T-Film
Slip Table Moving Mass	1191 lb (540.2285 kg)
Dimensions	74" x 74"
Pitch Moment Capacity	7.0×10^6 in-lb (790 kN-m)
Roll Moment Capacity	7.0×10^6 in-lb (790 kN-m)
Yaw Moment Capacity	2.16×10^5 in-lb (75 kN-m)

Facility 411 – Unholtz-Dickie T2000-3 Shaker



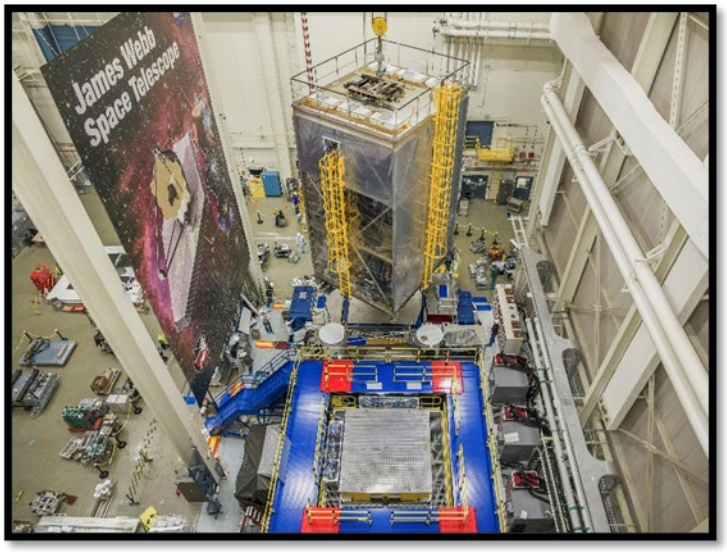
Usable Frequency Range	5 – 3000 Hz
Amplifier Model	2XSAI180 – T2000 (360 kVA)
Maximum Force (Sine)	25,000 lbf (111 kN) pk
Maximum Force (Random)	23,000 lbf (102 kN) rms
Maximum Displacement (Continuous duty)	2.7” pk-pk
Maximum Displacement (Intermittent duty)	3.0” pk-pk
Maximum Velocity (Sine)	80 in/s (2.0 m/s)
Maximum Velocity (Shock)	235 in/s (6.0 m/s)
Maximum Acceleration	125 G’s
Shaker Internal Load Support	1,500 lbs (680 kg)
Armature Mass	110 lb (49.8952 kg)
Slip Table	None (Vertical Testing Only)

Facility 412 – Unholtz-Dickie T2000-3/C STA Shaker



Usable Frequency Range	5 – 2500 Hz
Amplifier Model	2XSAI180 (360 kVA)
Maximum Force (Sine)	25,000 lbf (171 kN) pk
Maximum Force (Random)	23,000 lbf (102 kN) rms
Maximum Displacement (Continuous duty)	2.7” pk-pk
Maximum Displacement (Intermittent duty)	3.0” pk-pk
Maximum Velocity (Sine)	80 in/s (2.0 m/s)
Maximum Velocity (Shock)	235 in/s (6.0 m/s)
Maximum Acceleration	125 G’s
Shaker Internal Load Support	1,500 lbs (680 kg)
Armature Mass	110 lb (49.8952 kg)
Slip Table	CTSA/T2000-24-24
Slip Table Moving Mass	114 lbs. (51.7095 kg)
Dimensions	24” x 24”
Pitch Moment Capacity	5.0×10^6 in-lb. (790 kN-m)

Facility 430/431-1 – Data Physics LE-5022 Shakers



Usable Frequency Range	5-100 Hz
Vertical Mounting Interface	11’ x 11’ Guided Head Expander
Lateral Mounting Interface	11’ x 11’ Slip Table
Maximum Force (Sine)	50,000 lbf. pk
Maximum Displacement (Intermittent Duty)	3.0” pk-pk

Note: Please contact structural dynamics personnel for further information to ensure all test and facility requirements are met.

1.1.2 Acoustic Test Facility

Description: The Acoustic Test Facility at the Goddard Space Flight Center tests various sized scientific satellites, subsystems, and components. The facility consists of a reverberant chamber, acoustic horns, noise generators, control console, and a data acquisition system. The chamber can be operated as a class 100,000 clean room once the payload access doors are closed, and the facility is cleaned. When required, an anteroom, an anteroom is used for changing into clean garments before entering the facility through the personnel door.

Mode of Operation: The spectrum of the desired sound pressure level is programmed into the m+p Acoustic Control System. The payload is either suspended on the crane hook or mounted on a cart, dolly, or other fixture at the center of the chamber. Four to eight microphones are placed around the payload for control.

Acoustic energy is generated by modulating the flow of GN2 through the generator(s) attached to the horn(s). A fresh air forced ventilation system stabilizes the chamber pressure during operation of the facility and purges the chamber of GN2 for safe entry after the test.

Data Acquisition: Instrumentation data is acquired using the modular m+p digital data acquisition system. A large selection of accelerometers is available for instrumenting the test item.



Acoustic Chamber

Technical Specifications	
Max SPL (Empty Chamber)	152 dB
Horns/Generator	25 Hz Exponential/Wyle WAS 3000 50 Hz Hypex/Wyle WAS 3000
Frequency Range	25Hz – 10KHz
Acoustic Media	Gaseous Nitrogen
Microphones (4-8)	0-175 dB

Physical Characteristics	
Interior	33'L x 27'W x 42'H
Payload Access	14'11" W x 30'H
Personnel Door	3'W x 6'6" H
Crane Capacity	7.5 ton
Test Viewing	CCTV
Instrumentation Booms (2)	78 channels each

1.1.3 Mass Properties Measurement Facility (MPMF)

Description: The MPMF is used to measure the weight, center of gravity (CG), moment of inertia (MOI), and product of inertia (POI) of large structural assemblies. The facility can also be used to balance payloads statically and dynamically. The MPMF is portable and can be operated in clean rooms, or remotely operated in vacuum chambers at pressures down to 1.33 Kpa (10 torr).

Mode of Operation: The machine contains a spherical air bearing that supports the measuring table and the test item. The control console is remotely connected to the MPMF by flexible cables and a GN2 line. The console controls the table's motion and takes measurements of the unbalance moment, period of oscillation, and table rotational speed.

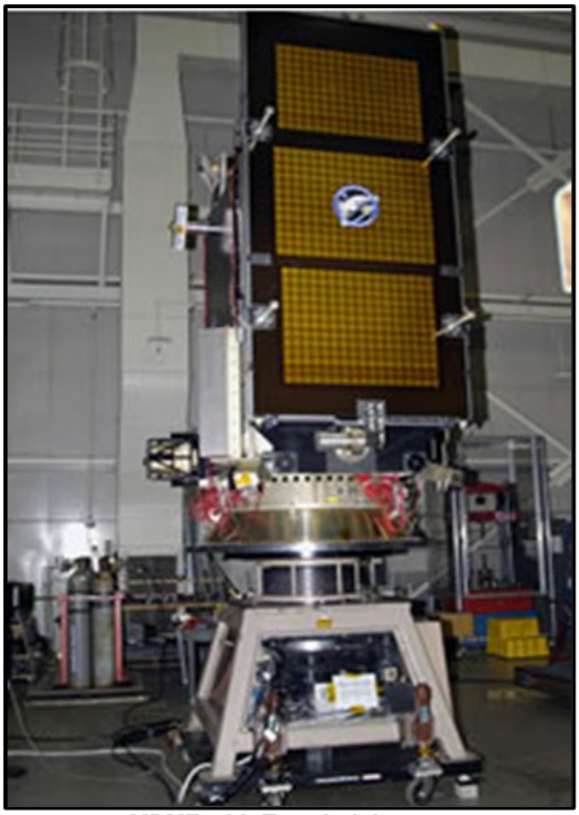
Weight Measurement: The facility is mounted on a Pennsylvania 6600 scale base platform (5.75' L x 5.75' W x 0.33' H) which gives an immediate digital readout of the weight of the test specimen, regardless of its mounting position on the facility.

CG Measurement: The static unbalance (CG offset) is determined by measuring the moment created by a CG displaced from the measurement axis of the machine.

MOI Measurement: The MOI is determined by using the facility as an inverted torsional pendulum and measuring the period of oscillation about the vertical axis of the machine.

POI Measurement: The POI (Dynamic unbalance) is determined by rotating the payload on the MPMF at several different speeds and measuring the moment.

Parameter	Specification
Test Weight (maximum)	10,000 lbs. (4,536 kg)
Table Dimensions	4’ (1.22 m) diameter mounting table
Moment Measurement Range (maximum)	30,000 in-lb. (3,390 Nm)
CG Accuracy	±0.06 "(0.15 cm) for payload at 3' (0.91 m) above table and displaced 1" (2.54 cm) from vertical axis ±0.12" (0.3 cm) for payload at 10' (3.1 m) above table and displaced 1" (2.54 cm) from vertical axis
MOI Accuracy	1% of measured MOI
POI Accuracy	5% of measured POI
MPMF Table Speed	0 to 200 RPM
Platform Scale Capacity	20,000 lb. (9,072 kg)
GN_2 Flow Rate	0.17 m^3/minute (6.0ft^3/minute) standard



MPMF with Test Article



MPMF without Hardware

1.1.4 High-Capacity Centrifuge

The High-Capacity Centrifuge (HCC) at Goddard Space Flight Center (GSFC) is used to simulate launch and landing loads on spacecraft hardware. Test items are installed on a test platform at the end of the arm. The platform utilizes a tilt fixture that will position the payload into the desired test orientation (clocking and tilt). The device can tilt a payload up to 10,000 lbs. The facility serviced by a 7.5-ton crane. The HCC is driven by two 1250 hp (0.93 Mw) DC Motors operated in conjunction with a motor generator set.



High-Capacity Centrifuge with GPM Structure

Technical Specifications	
Nominal Test Radius	60 feet
Maximum Test Acceleration	30 g's
Maximum Weight at 30 g's	5000 lbs. (payload & fixturing)
Maximum Platform Moment	7.5×10^6 in-lbs.
Tilt Fixture Limit	10,000 lbs.
Maximum Arm Speed	38.3 rpm
Crane Capacity	7.5 Ton
Data System Channel Count	128

1.1.5 Universal Static Test Facility

The Universal Static Test Facility is a structural steel framework designed for the application of multiple, individual statis loads to large spacecraft-sized test items and payload handling assemblies. Infinite mounting arrangements of hydraulic actuators allow simultaneous manually controlled loading multiple locations. Instrumentation including load cells, strain gages and displacement transducers can be installed, connected to, and monitored by a 128-channel data acquisition system. The Universal Static Test Facility is currently located in Building 15.



Express Logistics Carrier in the USTF

Parameter	Specification
Vertical Load	Up to 26,000 lbs. (11,794 kg)
Lateral Load	Up to 41,000 lbs. (18,598 kg)
Facility Modified Load	Up to 80,000 lbs. (36,288 kg)
Physical Characteristics	**Specification**
Internal Test Envelope	22’ L x 15’ W x 15’ H (6.7m x 4.6m x 4.6m)
Facility Weight	44,000 lbs. (19,958 kg)
Overhead Crane Capacity	15,000 lbs. (6,804 kg)

1.1.6 Universal Load Testing Machine

An MTS universal load test machine is used for tensile and compressive testing of small specimens and sub-assemblies, and for calibrating load cell transducers. The test article or connecting hardware is attached to the crosshead using various types of mounting hardware. Loads can be applied to the test article at controlled rates. Instrumentation including load cells, strain gages and displacement transducers can be installed, connected to, and monitored by a modular 128-channel data acquisition system. Output includes force vs. displacement. Raw data can be provided in a variety of formats. These include spreadsheets and graphs in a report format. The facility is in the building 7 Basement Vibration Lab.

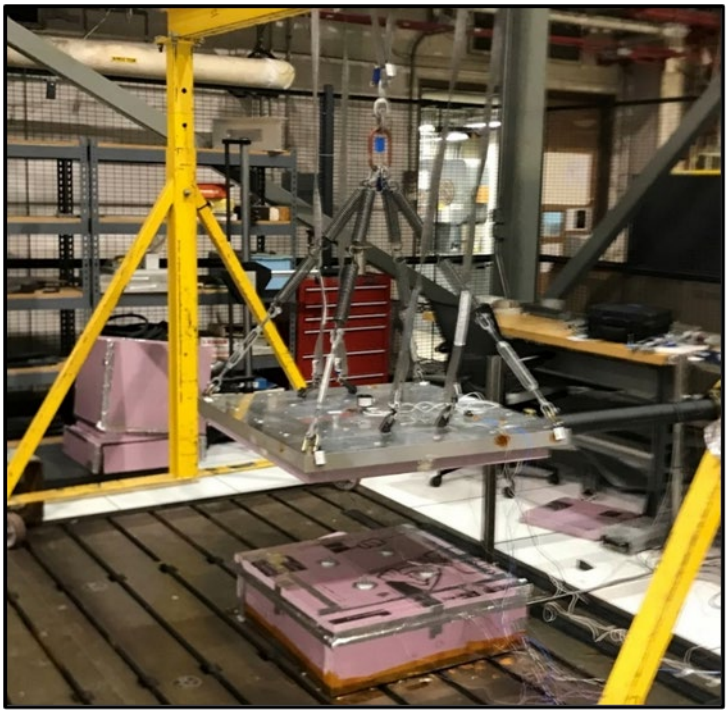


MTS Load Test Machine

Maximum Load Capacity	110,000 lbs. (500 kN)
Test Volume Width	30 in (762 mm)
Test Volume Minimum Height	16.8 in (427 mm)
Test Volume Maximum Height	82 in (2085 mm)

1.1.7 Modal Test Facility

The Modal Test Facility at Goddard Space Flight Center (GSFC) is used to measure dynamic response characteristics of aerospace structures. Test items are mounted to the facility seismic mass via a T-slot table to simulate a fixed boundary condition. The facility is serviced by three bridge cranes that provide a convenient method of supporting up to three electro-dynamic shakers. The facility is supported by a digital data acquisition system that has the capability to simultaneously record raw data time signals while processing the data into spectrums, FRF's, and coherence functions in real time. Post-test curve fitting algorithms within the group's modal analysis software extract the estimated modal parameters from the test data. The facility is in Building 15.



Modal Test Facility

Technical Specifications	
Max Excitation (Force)	100 lbf.
Excitation Freq Range	0.1 to 2 kHz
Available Shakers	2 lbf, 100 lbf
Available Modal Hammers	100 lbf, 5000 lbf
Data System Channel Count	256 max direct; 384 using breakout rack
T-Slot Table Dimensions	12 ft x 12 ft

1.2 ELECTROMAGNETIC TESTING

1.2.1 Electromagnetic Compatibility and Interference (EMC/EMI) Testing

Introduction: Two semi-anechoic shielded test facilities are available for performing Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) tests. These facilities meet performance requirements specified by MIL-STD and "General Environmental Verification Specification" (GEVS). Both facilities provide very low level ambient electromagnetic environments and the ability to contain internally generated, radiated electromagnetic waves. All electrical power, communications, and other facility wiring are filtered; the facility structures are locally bonded to Earth ground; and verification ducts and other apertures are designed as waveguide-below-cutoffs. Contamination-sensitive items are typically tested in the Large EMC Facility (Class 10k cleanroom), or they are bagged in RF Transparent materials (Melinex) with GN2 (Gaseous Nitrogen) purge, if tested in the Small EMC Facility.

Integral Instrumentation: Frequency based emission measurements are typically made using a Rohde and Schwarz FFT (Fast Fourier Transform) EMI receiver (ESW44), but the facility also has traditional EMI receivers and spectrum analyzers. Time domain scans are typically performed using the Tektronix MSO series of oscilloscopes and can perform low and high-power measurements. The test equipment is controlled by numerous COTS software packages (EMC32, TILE!) and some custom GSFC LabView programs.

Associated electric and magnetic field antennas and current probes are provided for testing in the 20 Hz to 40 GHz frequency range for both emissions and susceptibility testing. Conducted and radiated susceptibility tests are performed using a variety of signal generators, amplifiers, transducers, and antennas for injection and/or radiation of the test signals. Radiated field strengths up to 150 V/m can typically be provided.

Data Acquisition: The Rohde and Schwarz EMC32 EMC software is primarily used for conducted and radiated emission measurements. TILE! Software is predominantly used for conducted and radiated susceptibility testing as well as for unique one-off tests supporting ISS (Internation Space Station) power quality. Project and facility test computers will be synchronized to determine susceptibility thresholds defined by project requirements to determined how the test item responds to the susceptibility test signal.

Electrical Power: Test item power is normally provided by project-furnished electrical ground support equipment, power supplies. A high-power programmable power supply has the capability to provide power to test articles while producing power quality waveforms. Each EMI shielded enclosure (test cell, EGSE, EMI control room) is supplied with filtered power and can be modified to handle higher power applications with the proper amount of preparation.

1.2.1.1 Small EMI Facility

Description: This facility is in Building 7, Room 008 and is designed for either small satellite or sub-assembly tests. This facility consists of three contagious electromagnetically shielded enclosures that meet or exceed shielding effectiveness requirements stated in IEEE-299. The individually shielded enclosures include the anechoic Test Room, the EMC Control Room, and a Ground Support Equipment (GSE) Room. Inside the Test Room is a free-standing faraday cage that is lined with ferrite tiles with TDK IP-090, carbon impregnated Styrofoam wedge absorbers to handle RF energy absorption up to 200 V/M (70mW/cm2) from 20 Hz to 40 GHz. The Control and GSE Rooms consists of standard modular shielded panels constructed of ¾" plywood paneling, sandwiched by an inner and outer layer of 10 mil galvanized steel. A cable penetration plate, located on the same wall as the test bench, separates the Test Room from the GSE Room and acts as a Single Point Ground for both the spacecraft and GSE. The standard penetration plate consists of four "Pi" filters and three 3" diameter Wave-Guide-Below cutoffs that can be used to feed cables through. When desired a penetration plate can be made to mount existing TVAC cables to reduce cable costs and to reduce common mode currents.

Mode of Operation: The test article is installed in the EMC chamber and bonded to the copper test bench that is certified to hold a 250-pound payload (5:1 tested to 1250 lbs.). The test bench is bonded to the anechoic panels via a copper ground strap which maintains a 5:1 (length: width) ratio. Interconnecting cables between the test article and its ground support equipment are connected through an access panel mounted either on the cleanroom or GSE side, allowing for greater flexibility and acting as a single point ground. The test enclosure maintains relative humidity between 30% and 70% and temperature at 68°F ±5° (20°C ±2.8°).

Physical Characteristics:

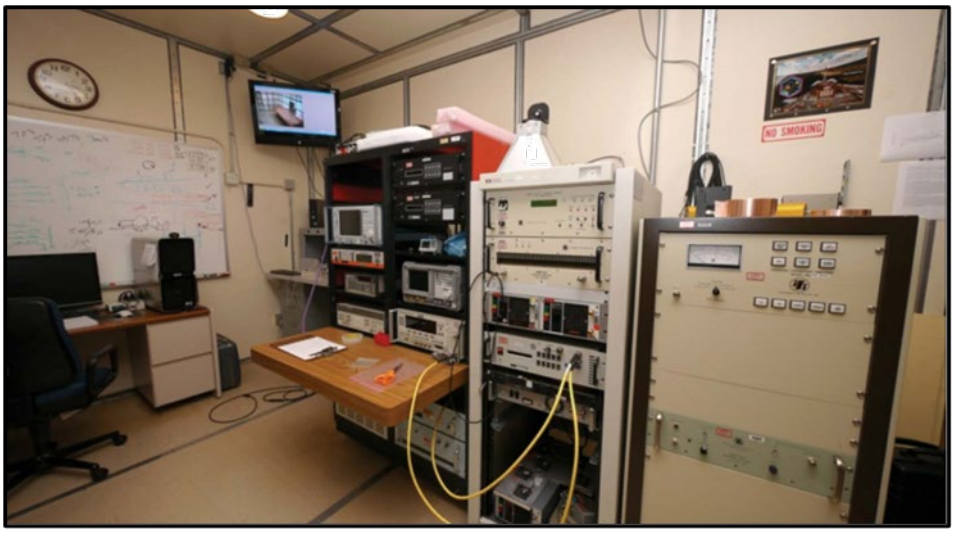
Experimenter's Area: 4 m (L) x 2 m (W) x 3 m (H) / Personnel Door: 1 m (w) x 1.7 m (H)

Control Room: 7.3 m (L) x 5 m (W) x 3 m (H) / Personnel Door: 1.3 m (W) x 2.1 m (H)

Test Area Room: 5.5 m (L) x 5 m (W) x 3 m (H) / Equipment Door: 2 m (W) x 2.2 m (H)

Test Area Anechoic Characteristics: Ferrite tiles and Carbon impregnated Styrofoam wedge absorbers combine to make the facility a broadband anechoic chamber capable of absorbing electromagnetic waves over the frequency range of 20 Hz to 40 GHz. Field measurement accuracy is thereby enhanced compared to shield room facilities that lack the anechoic material, and radiated susceptibility test signals are controlled with improved signal-to-noise ratios. The test facility also has web-based video camera system and Fiber Optic lighting capable of withstanding 200 V/M that keeps the facility RF emissions to a minimum.

Fire Protection: Fire protection is provided in the Test Area using retractable sprinkler heads and an auto-cutoff ventilation system for toxic smoke exhaust to the outside of the building. The TDK IP-090 Carbon impregnated Styrofoam wedge absorbers release CO2 and water vapors when ignited. Personnel safety features include a radiation hazard warning and monitoring system. The facility is also equipped with electrostatic discharge testing and prevention capabilities and a large copper test bench for mounting and earth-bonding test items.



Small EMC Control Console



Small EMC Shielded Enclosure



Small EMC Ground Support Equipment Room

1.2.1.2 Large EMC Facility

Description: This facility is in Building 7, Room 108A and is designed for testing large spacecraft that require Class 10k contamination protection. This facility consists of three contiguous electromagnetically shielded enclosures that meet or exceed shielding enclosure requirements stated in IEEE-299. The enclosures consist of Test Room (Rm. 108A), the EMC Control Room (Rm. N115), and a Ground Support Equipment (GSE) Room (Rm. N117). Inside the enclosure is a free-standing faraday cage that is lined with ferrite tiles with Panashield HYB-NF12, fibrous composite material with carbon impregnated within wedge absorbers to handle RF energy absorption up to 200 V/M (70mW/cm2) from 20 Hz to 40 GHz. The Control and GSE Rooms consist of standard modular shielded panels constructed of ¾" plywood paneling, sandwiched by an inner and outer layer of 10 mil galvanized steel. A cable penetration plate, located on the same wall as the test bench, separates the Test Room from the GSE Room and acts as a Single Point Ground for both the spacecraft and GSE.

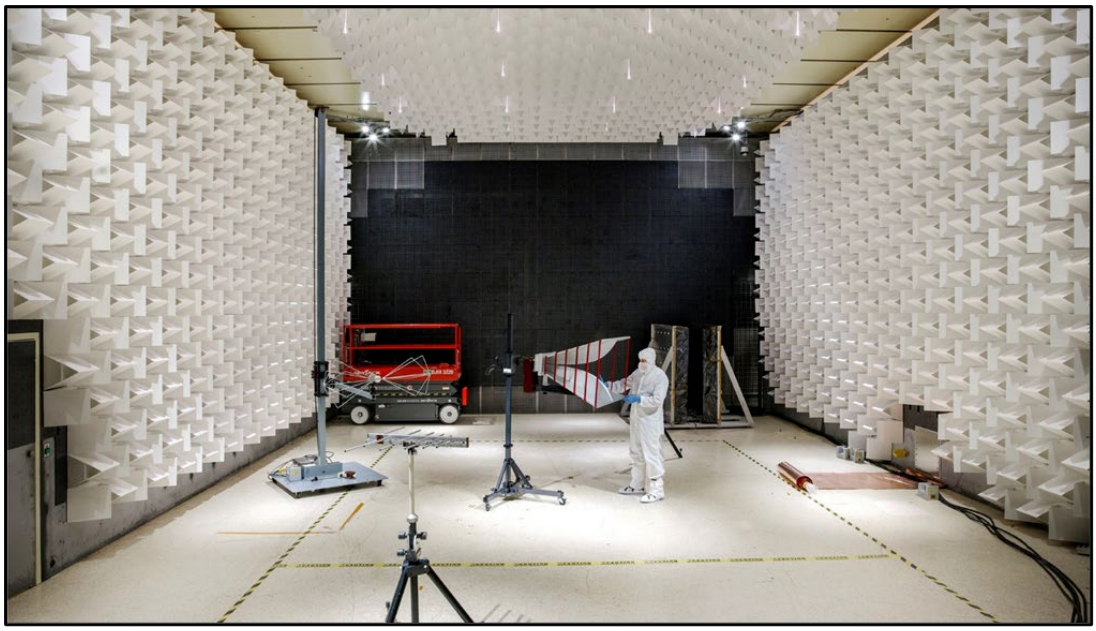
Mode of Operation: The test article is installed inside the faraday cage and bonded to the penetration plate ensuring a single point ground for project and EMI test equipment. Grounding for larger spacecraft, that can't fit onto the test bench, can connect to either an 18" or 36" wide copper strap for a better RF ground and maintaining a 5:1 (length: width) ratio. Interconnecting cables between the test article and its ground support equipment are connected through an access panel mounted either on the cleanroom or GSE side, allowing for greater flexibility and acting as a single point ground. The test enclosure maintains a relative humidity at a value between 30% and 70% and temperature at 68°F ±5° (20°C ±2.8°).

Physical Characteristics:

Test Enclosure Size:	Expandable from basic 6.5m cubed. Max Height: 6.7 m
Ferrite-Tiled Anechoic Enclosure Door Size:	6.5 m (W) x 6.2 m (H)
Ground Support Equipment Enclosure:	Room Size: 6.7 m (L) x 5.2 m (W) x 3.2 m (H) Door Size: 2 m (W) x 2.5 m (H)

Test Area Anechoic Characteristics: Ferrite tiles with Panashield HYB-NF12, fibrous composite material with carbon impregnated within, absorbers handle RF energy absorption up to 200 V/M (70mW/cm2) from 20 Hz to 40 GHz are mounted on the interior walls of the test area combine to make the facility a broadband anechoic chamber capable of absorbing electromagnetic waves over the frequency range of 20 Hz to 40 GHz. Field measurement accuracy is thereby enhanced compared to shield room facilities that lack the anechoic material, and radiated susceptibility test signals are controlled with improved signal-to-noise ratios. The test facility also has web-based video camera system capable of withstanding 200 V/m and just like the Fiber Optic lighting, keeps RF emissions to a minimum.

Safety Features: The Test Enclosure is equipped with flashing warning lights at all entrance doors to warn personnel not to enter whenever electromagnetic waves are being propagated within the room. Internal humidity and temperature alarms, as well as a fire alarm and dry sprinkler system, are also features of this facility. ¾" plywood paneling, sandwiched by an inner and outer layer of 10 mil galvanized steel. A cable penetration plate, located on the same wall as the test bench, separates the Test Room from the GSE Room and acts as a Single Point Ground for both the spacecraft and GSE.



Large EMC Shielded Enclosure



Large EMC Control Console

1.2.2 Magnetic Testing

Introduction: The remotely located Magnetics Test Site contains two major coil systems, 6.7 m (22') and 12.8m (42'), used for magnetic testing of payloads ranging from fully configured spacecraft down to component level assemblies; and for calibrating torque coils and magnetometers in attitude control systems. Both facilities are 3-axis Braunbek coil systems consisting of 12 coils (four coils for each of three orthogonal axes.) Each coil contains windings for Earth's field cancellation, static, and dynamic field generation, diurnal variation control, temperature gradient compensation, external gradient compensation, and two sets of spare windings.

Control consoles for both coil systems are in separate buildings apart from the coils. This isolation prevents control equipment magnetic fields from degrading the specified magnetic environment established within the Braunbek coils. For both coils, static and dynamic (0-100 rad/sec) field vectors can be generated along any axis with magnitudes of up to 60,000 nanotesla (nT.)

1.2.2.1 6.7M (22') Coil Magnetic Test Facility

Description: The Magnetic Field Component Test Facility (MFCTF) contains a 6.7 m (22') diameter spherical coil system. This system provides geomagnetic field cancellation within a 0.9 m (3') diameter sphere to levels described below. This coil system is used primarily for testing smaller satellites, performing instrument-level dipole moment measurements, and for calibrating magnetometers and attitude control systems.

Mode of Operation: For a typical magnetometer test, a zero field is established in the center of the coils before the test unit is installed. A reference standard proton magnetometer is then used to calibrate the system. Following this, the test magnetometer is positioned on the platform at the center of the coil and aligned to the coil axes. Finally, static, and dynamic fields are generated to establish linearity, frequency response, zero offset, and alignment characteristics of the magnetometer.

Static Field Capability		Dynamic Field Capability	
Magnitude (each axis):	±60,000 nanotesla	Magnitude (each axis):	±60,000 nanotesla
Resolution:	±0.1 nanotesla	Resolution and Stability:	±2%
Stability:	±0.5 nanotesla	Frequency:	0 To 100 rad/sec
Homogeneity:	0.001% (0.91 m, 3' Diaspherical volume)		

Physical Characteristics:
Coil Access Opening: 1.52m W x 1.52m H (5' x 5')
Building Access Opening: 3.05m W x 3.05m H (10' x 10')

Integral Instrumentation: The MFCTF is equipped with instrumentation for the calibration and alignment of magnetometers. This instrumentation includes fluxgate and proton magnetometers for zeroing and calibrating. A data acquisition/analysis system is available to acquire magnetometer data, perform near field analysis, and produce a customer-ready report.

1.2.2.2 12.8M (42') Coil Magnetic Test Facility

Description: The Spacecraft Magnetic Test Facility (SMTF) 12.8 m (42') coil system is one of the three known spherical coil systems of this size in the world. Its geomagnetic field cancellation system can cancel the Earth's magnetic field within a 1.83 m (6') diameter sphere. The SMTF also has a set of 2.90 m (9.6") diameter Helmholtz coils available for perming and deperming spacecraft, and 1.22 m (4') and 1.83 m (6') diameter coils for magnetically cleaning smaller test items.

Mode of Operation: Magnetic Dipole Moment Testing: Zero-Field is first established in the center of the coil. A reference standard proton magnetometer is used to calibrate the coils. For each measurement sequence, the test item and facility dolly are moved to the center of the coil. As the dolly is rotated 360 degrees, three-component magnetic field data is obtained at 10-degree increments. The data are then stored in the computer for immediate display and processing. If the test items exceed its test limit, compensation magnets can be developed to reduce the dipole moment to acceptable levels.

Spacecraft Magnetometer Calibration: Initial setup is like magnetic dipole moment testing. The test item is positioned in the center of the coil and aligned with the coil axes. Static and dynamic fields are generated to establish linearity, frequency response, zero offset, and alignment characteristics of the test item. The data system can be used to collect, store, and display test parameters.

Static Field Capability		Dynamic Field Capability	
Magnitude (each axis):	±60,000 nanotesla	Magnitude (each axis):	±60,000 nanotesla
Resolution:	±0.1 nanotesla	Resolution and Stability:	±2%
Stability:	±0.5 nanotesla	Frequency:	0 To 100 rad/sec
Homogeneity:	0.001% (1.83 m, 6' Diaspherical volume)		

Physical Characteristics:

Coil Access Opening:	3.05m W x 3.05m H (10' x 10')
Building Access Opening:	4.27m W x 4.57m H (14' x 15')
Hoists Lifting Capacities (4):	4,536 Kg (5 Ton), 2,722 Kg (3 Ton), and two each 2,268 Kg (2.5 Ton)

Integral Instrumentation: The SMTF is equipped with single and triaxial magnetometers, proton magnetometers, torque meter, and data collection instrumentation. It contains the three Helmholtz coils described above, with their associated AC and DC power supplies.



42’ Coil Magnetic Test Facility

Data Acquisition: An array of three state-of-the-art triaxial fluxgate magnetometers is used for magnetic field testing. A field mapping of the test item is performed, the resultant data is automatically provided as input into the facility’s “near field analysis” software, and an equivalent dipole moment is calculated. Measurements are taken for various magnetic field conditions including perm, deperm, induced, and stray field (test item powered) measurements.



Test Area Close-Up View

1.2.2.3 Traveling Magnetics Test Set

Description: The Traveling Magnetics Test Set is available to perform magnetic tests in a variety of locations and configurations due to its portability. It consists of 4 magnetometers controlled by a custom-built magnetometer control unit. The portable test set can perform measurements of static magnetic fields, dynamic magnetic fields, and magnetic dipole moment. Dipole moment tests will require a cart, turntable, or other support structure that can be rotated 360 degrees. Tests with this portable system can be performed at facilities across the United States. Tests are typically performed at night to reduce the magnetic field disturbances of human activity, such as metal doors opening and cars driving nearby. Data from static and dynamic field tests can be provided as time-series plots in terms of maximum or average values. Data from dipole moment tests can be provided as a graph, as a table of individual measurements, and as the calculated dipole moment's X, Y, and Z axis components and magnitude.



Magnetics Test Set



Magnetics Test in Action

1.3 SPACE SIMULATION TESTING

Introduction: This section provides a summary of the environmental capabilities and dimensions of the test facilities controlled by the Space Simulation Test Engineering Group. The test volume measurements provided are nominal dimensions of the thermal shroud for chambers that have a shroud. Pumping speeds provided are the manufacturer's stated speeds at the pump opening.

The test facilities are operated and monitored 24 hours per day. Test setups and teardowns are performed during normal working hours unless other arrangements are made in advance. The Space Simulation Test Engineering Group Lead and Test Engineers provide customers with cost estimates, chamber availability and technical support. A Thermal Vacuum Orientation Package is also available to help customers understand documentation, operation, safety, schedule, and technical requirements.



Building 7 Thermal Vacuum Chambers View

Capabilities Summary

The following table displays the nominal specifications for each of our facilities. Please consult a Code 549 Space Simulation Test Engineer for the most up-to-date capabilities.

Facility	Nominal Specifications				
Type	**Facility Number**	**Test Volume**	**Operating Pressure**	**Temperature Range**	**Unique Capabilities**
Temperature	204	19.7 x 23.6 x 29.5 in 50 x 60 x 75 cm	Ambient	-70 to +180°C 203 to 453°K	
Temperature and Humidity	232	4 x 4 x 4 ft 1.22 x 1.22 x 1.22 m	Ambient	-95 to +150°C 178 to 423°K	Humidity <5% to 95% RH (±5%)
	233	4 x 4 x 4 ft 1.22 x 1.22 x 1.22 m	Ambient	-70 to +150°C 203 to 423°K	Humidity <5% to 95% RH (±5%)
Thermal Vacuum	225	9 Dia x 14 L ft 2.74 Dia x 4.27 L m	<1x10^{-5} torr <1.33 mPa	-142 to +156°C 131 to 429°K	LN_2 shroud, 2 Cryopumps, Turbopump, C/F, S/P, 2 TQCMs, RGA
	237	7 Dia x 8 L ft 2.13 Dia x 2.44 L m	<1x10^{-5} torr <1.33 mPa	-140 to +129°C 133 to 402°K	LN_2 shroud, Diffusion Pump, C/F, S/P, TQCM, RGA
	238	12 Dia x 15 H ft 3.66 Dia x 4.57 H m	<1x10^{-5} torr <1.33 mPa	-118 to +114°C 155 to 387°K	LN_2 shroud, 3 Cryopumps, Turbopump, C/F, S/P, 2 TQCMs, RGA
	239	7 Dia x 8 L ft 2.13 Dia x 2.44 L m	<1x10^{-6} torr <0.13 mPa	-148 to +117°C 125 to 390°K	Cryopump, C/F, S/P, 2 TQCMs, RGA
	240	3 Dia x 3 L ft 0.91 Dia x 0.91 L m	<1x10^{-5} torr <1.33 mPa	-107 to +116°C 166 to 389°K	Diffusion Pump, C/F, S/P, TQCM, RGA
	241	3 Dia x 4 L ft 0.91 Dia x 1.22 L m	<1x10^{-5} torr <1.33 mPa	-160 to +150°C 113 to 423°K	Cryopump, C/F, S/P, TQCM, RGA
	245	2 Dia x 3 L ft 0.61 Dia x 0.91 L m	<1x10^{-5} torr <1.33 mPa	+20 to +145°C 295 to 423°K	Turbopump, C/F, TQCM, RGA
	246	3.5 Dia x 5.5 L ft 1.06 Dia x 1.68 L m	<1x10^{-6} torr <0.13 mPa	-140 to +150°C 133 to 423°K	Cryopump, C/F, S/P, TQCM, RGA
	281	3 Dia x 4 L ft 0.91 Dia x 1.22 L m	<1x10^{-5} torr <1.33 mPa	-140 to +150°C 133 to 423°K	LN_2 shroud, Cryopump, C/F, S/P, TQCM, RGA
	290	27 Dia x 40 H ft 8.23 Dia x 12.2 H m	<1x10^{-6} torr <0.13 mPa	-80 to +80°C 193 to 353°K	LN_2 shroud, 7 Cryopumps, Turbopump, He Shroud, C/F, S/P, 4 TQCMs, RGA
Rapid Pump Down	208	N/A	<1x10^{-2} torr <2.67 Pa	N/A	Rough down Facilities 237 & 239 in 2 minutes
Thermal Conditioning Units	201	N/A	N/A	-140 to +140°C 133 to 413°K	GN_2 transfer medium/circulating, available LN_2 bypass mode
	202	N/A	N/A	-140 to +140°C 133 to 413°K	GN_2 transfer medium, single pass
	203	N/A	N/A	-140 to +140°C 133 to 413°K	GN_2 transfer medium/single pass, available LN_2 bypass mode
Heater Racks	315	N/A	N/A	-140 to +140°C 133 to 413°K	12 circuits, 4 can be used for Zero-Q
	316	N/A	N/A	-140 to +140°C 133 to 413°K	12 circuits
Emergency Power	253	N/A	N/A	N/A	250 kVA, 480 V, 3-phase
	254	N/A	N/A	N/A	350 kVA, 480 V, 3-phase
High Pressure GN_2	257	N/A	N/A	N/A	2000 psi 13.79 MPa
	258	N/A	N/A	N/A	2000 psi 13.79 MPa

Note: The nominal specifications listed here and throughout this handbook are current at the time of publication. Please consult a Code 549 Space Simulation Test Engineer for the most up-to-date capabilities.

1.3.1 Temperature – Humidity

1.3.1.1 Facility 204 – 0.227m^3 (8 ft^3) Temperature Chamber

Description: Espec EPZ-2H Test Chamber. This facility is a small temperature-controlled chamber used for thermal conditioning of small components. The portable chamber loads through a front opening door. Payloads can be installed inside on the floor or on a stainless-steel grated shelf. A port is available on the left side for instrumentation and connections to a ground support equipment, if necessary.

Mode of Operation: The chamber is cooled with a cascade 2.2hp hermetic refrigeration system and heated with electrical resistance elements.

Parameters:

Temperature Range:	-70°C to +180°C (203°K t0 453°K)

Physical Characteristics:

Test Volume (W x D x H):	19.7" x 23.6" x 29.5" (50 x 60 x 75 cm)
Access Port Size:	6" (15.24 cm)
Power:	208 VAC, 3 Phase, 40A

Integral Instrumentation: Temperature is controlled by a digital programmer/controller located on the side of the chamber. A portable data system may be utilized to monitor the condition of the test articles within.



Temperature Chamber (Facility 204)

1.3.1.2 Facility 232 – 1.81 m^3 (64 ft^3) Temperature – Humidity Chamber

Description: This facility is a medium-sized chamber used for thermal and humidity cycling of medium-sized test items. A full opening hinged front door with a window allows for access and viewing.

Mode of Operation: The test item is installed in the chamber and connected to an external power source and data acquisition equipment via an access port. After ambient functional checks are completed, electrical heaters warm, and a cascade refrigeration system cools the air stream. A separate cooling unit provides dehumidification, and an electrically heated vapor generator provides humidification. The preferred procedure is to operate the chamber with a hot cycle before decreasing the temperature below 4°C (277°K). A dry nitrogen purge system regulates humidity in the chamber to prevent frost build-up on the test item. Five integral gloves can be provided in the front door of the chamber for "glove box" type testing of mechanisms, etc. Project EGSE can connect with test articles via these same access ports.

Parameters:

Temperature Range:	-95°C to +150°C (178°K to 453°K)
Humidity Capacity (RH):	15% to 95% (between 85°C [358°K) max and 4°C (277°K) min dewpoint); <5% with nitrogen purge
Heating Capacity:	18kW
Cooling Capacity:	22kW
Max P/L weight:	200 lbs. (90kg)

Physical Characteristics:

Test Volume (W x D x H):	4' x 4' x 4' (1.22 x 1.22 x 1.22 m)
Viewport Size:	24" x 24" (61 x 61 cm)
Access Port Size:	6" (15.2 cm)

Integral Instrumentation: Temperature and humidity are controlled by a digital programmer/controller located on the side of the chamber. Eighteen thermocouples are available for payload monitoring.



Temperature – Humidity Chamber (Facility 232)

1.3.1.3 Facility 233 – 1.81m³ (64ft³) Temperature – Humidity Chamber

Description: This facility is a medium-sized chamber used for thermal and humidity cycling of medium-sized test items. A full opening hinged front door with a window allows for access and viewing.

Mode of Operation: The test item is installed in the chamber and connected to an external power source and data acquisition equipment via an access port. After ambient functional checks are completed, electrical heaters warm, and a cascade refrigeration system cools the air stream. The preferred procedure is to operate the chamber with a hot cycle before decreasing the temperature below 4°C (277°K). A dry-air and dry nitrogen purge system regulates humidity in the chamber to prevent frost build-up on the test item. Integral gloves can be provided in the front door of the chamber for "glove box" type testing of mechanisms, etc. Project EGSE can connect with test articles via these same access ports.

Parameters:

Temperature Range:	-67°C to +150°C (203°K to +423°K)
Humidity Range:	(RH): 15% to 95% (between 85°C (358°K) max and 4°C (277°K) min dewpoint); <5% with nitrogen purge
Heating Capacity:	18 kW
Cooling Capacity:	22 kW
Max P/L Weight:	200 lbs (90 kg)

Physical Characteristics:

Test Volume (W x D x H):	4' x 4' x 4' (1.22 x 1.22 x 1.22 m)
Viewport Size:	24" x 24" (61 x 61 cm)
Access Port Size:	6" (15.2 cm)

Integral Instrumentation: Temperature and humidity are controlled by a digital programmer/controller located on the side of the chamber. Eighteen thermocouples are available for payload monitoring.



Temperature – Humidity Chamber (Facility 233)

1.3.2 Thermal Vacuum

1.3.2.1 Facility 225 – 2.7 m x 4.3 m (9' x 14') Vacuum Chamber

Description: This is a horizontal loading thermal vacuum test chamber used for thermal vacuum and thermal balance testing and baking out large test items. Electrical feedthroughs and liquid and gas penetrations are provided at locations on the sides and rear of the chamber. A clean tent covering the door opening provides Class 10,000 clean area for integrating hardware prior to loading it into the chamber.

Mode of Operation: Test items are loaded by crane onto a load cart, which is rolled into the chamber on a rail system. Payload weight can be as high as 3,000 lbs (1,361 kg). Access to the chamber is through a clean tent. The use of cleanroom procedures and the wearing of clean garments are required when working in the chamber.

Chamber evacuation is provided by two cryopumps and one turbomolecular pump. Roughing is provided by a blower and rotary piston mechanical pump. Shroud temperature conditioning is accomplished by a recirculating GN2 thermal system, or it may be flooded with LN2.

Parameters:

Test Pressure:	$<1x10^{-5}$ Torr (<1.33 mPa)
Shroud Temperature:	
GN2 mode:	-142°C to +156°C (131°K to 429°K)
LN2 mode:	-190°(83°K)
Pumping Speeds for N2:	
2 Cryopumps:	127,000 cfm (60,000 l/s)
Turbomolecular pump:	2,120 cfm (1,000 l/s)

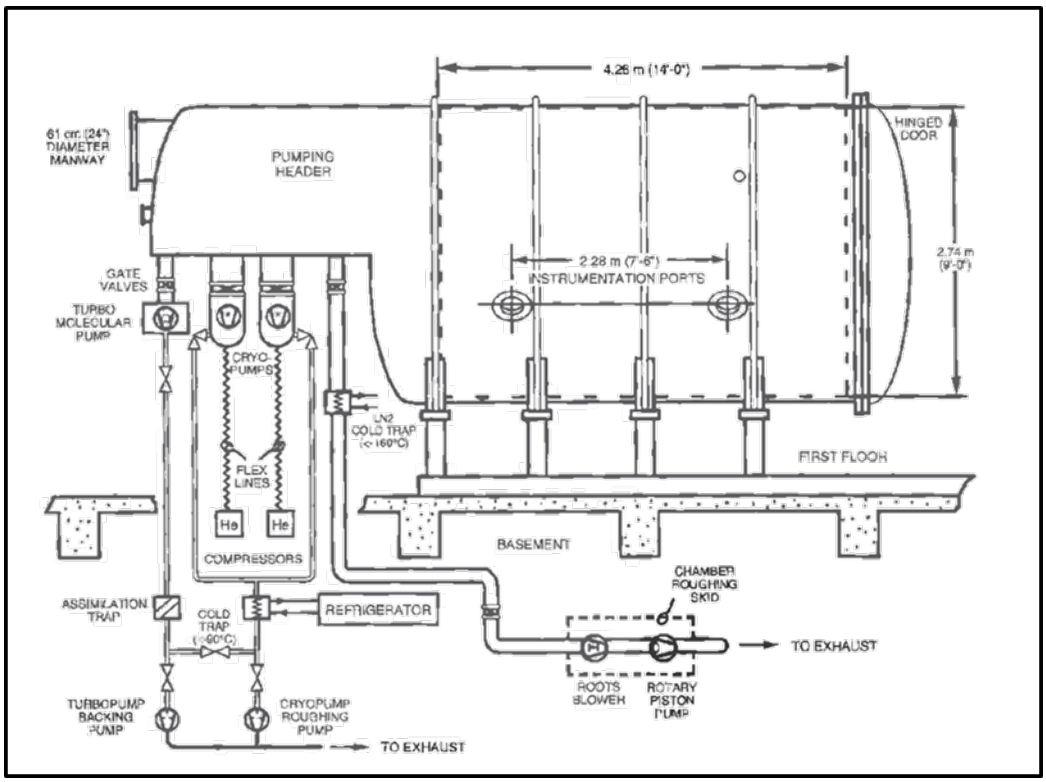
Physical Characteristics:

Test Volume:	9' dia x 14' L (2.74 x 4.27 m)
Payload Support:	4.2' x 10.7' cart – 3,000 lb (1,361 kg) capacity
Crane Capacity:	4,536 kg (5 ton)
Instrumentation Ports:	6 each 25.4 cm dia (10"), 6 each 12.7 cm dia (5")
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

Integral Instrumentation:

Pressure:	Convection – atm to 10^{-3} Torr
	Ion gauge – 10^{-3} Torr to ultimate
Payload Temperature:	320 channels
Contamination:	TQCM, scavenger plate, cold finger, residual gas analyzer

Auxiliary Equipment: Portable thermal systems are available to control baseplates, the payload cart, the thermoelectric quartz crystal microbalance (TQCM) and contamination control mirrors. Additionally, the payload cart has piping for auxiliary heating and cooling and six bar heaters installed to increase transition rates.



Facility 225 Chamber and Vacuum System Schematic



Facility 225

1.3.2.2 Facility 237 – 2.1 m x 2.4 m (7' x 8') Diffusion-Pumped Vacuum Chamber

Description: This is a horizontal loading thermal vacuum test chamber. An overhead rail is available for mounting purposes and stainless-steel rods are available for hanging thermal blankets. The facility is used for thermal vacuum and thermal balance testing and baking out test items.

Mode of Operation: The test item is lifted by crane or hand carried onto the payload cart positioned at the chamber door. Typically, the payload is instrumented and connected to GSE prior to rolling it into the chamber. Ground support equipment cabling is connected through penetration plates and ambient functional checks are performed.

Chamber evacuation is provided by a rotary piston mechanical pump and an oil diffusion pump. Rapid pump down can also be performed. A sliding gate main valve allows chamber access while the pumping systems are established.

Parameters:

Test Pressure:	$<1x10^{-5}$ Torr ($<2x10^{-7}$ psi)
Shroud Temperature:	
GN2 Mode:	-140°C to +129°C (133°K to +402°K)
LN2 Mode:	-190°C (83°K)
Diffusion Pump Speed for N_2:	25,000 l/s (53,000 cfm)

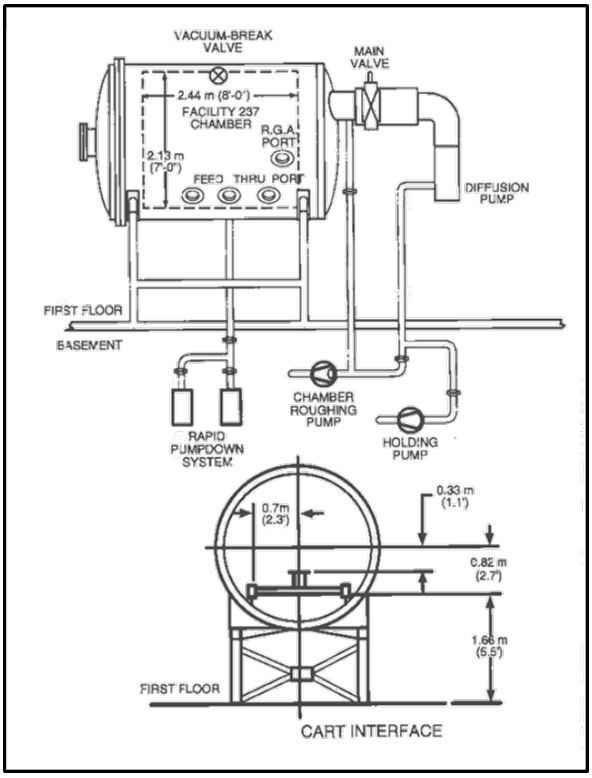
Physical Characteristics:

Test Volume:	2.13 m dia x 2.44 m L (7' x 8')
Payload Support:	44" x 76" cart – 584 kg (1288 lb) capacity
	43.5" x 80" cart – 729 kg (1607 lb) capacity
Crane Capacity:	4,536 kg (5 Ton)
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

Integral Instrumentation:

Pressure:	Convectron – atm to 10^{-3} Torr
	Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	126 channels
Contamination Monitors:	TQCM, scavenger plate, cold finger, residual gas analyzer

Auxiliary Equipment: Heater racks and thermal conditioning units (TCUs) are available to control auxiliary heater panels, cryo-panels, and baseplates.



Facility 237 Chamber and Vacuum System Schematic



Facility 237

1.3.2.3 Facility 238 – 3.7 m x 4.6 m (12' x 15') Cryo & Turbo Vacuum Chamber

Description: This is a vertical loading thermal vacuum test chamber used for thermal vacuum and thermal balance testing and baking out spacecraft hardware. A bracket containing stainless-steel tubes is available for hanging thermal blankets. Ports for electrical feedthroughs and liquid/gas feedthroughs are located around the perimeter of the chamber. A clean tent at the chamber entrance provides class 10,000 cleanliness conditions.

Mode of Operation: Test articles are normally loaded through the top of the chamber using the building crane; however, small payloads can be transported through the personnel entrance. In some cases, special fixtures must be designed due to the uniqueness of the test article support system. Once installed, the payload is connected to the ground support equipment via feedthroughs. Access to the chamber is through a clean tent. The use of cleanroom procedures and the wearing of clean garments are required when working in the chamber.

Initial chamber evacuation is provided by two rotary piston mechanical pumps, with three cryopumps and a turbomolecular pump for high vacuum pumping. All four pumps are isolated from the chamber by sliding gate main valves.

Parameters:

Test Pressure:	$<1x10^{-5}$ Torr ($<2x10^{-7}$ psi)
Shroud Temperature:	
GN2 Mode:	-118°C to +114°C (155°K to +387°K)
LN2 Mode:	-190°C (83°K)
Pumping Speeds for N2:	
3 cryopumps	90,000 l/s (190,700 cfm)
Turbomolecular Pump	2,000 l/s (4,237 cfm)

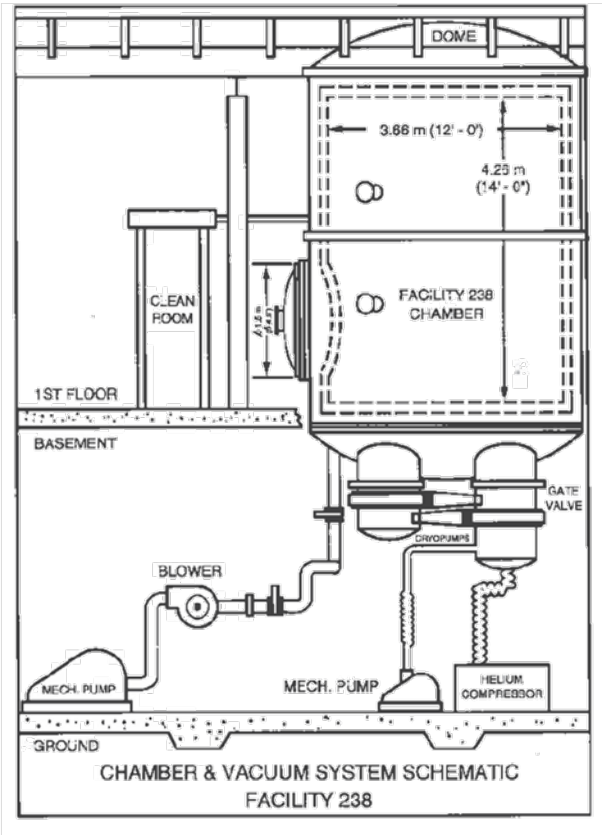
Physical Characteristics:

Test Volume:	3.4 m D x 4.3 m H (11'2" x 14'2")
Personnel Door:	1.5 m (5') diameter
Payload Support:	Floor Level – 1.2 m (4') square platform – 1950 kg (4300 lb) capacity Side Wall – Hard Points at 1.8 m and 3.7 m (6' and 12') levels
Crane Capacity:	4,536 kg (5 Ton)
Crane Hook Height:	4.06 m (13'4") to dome stop, 4.16 m (13'8") to top flange
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

Integral Instrumentation:

Pressure:	Convectron – Atm to 10^{-3} Torr Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	360 channels
Contamination Monitors:	TQCM, scavenger plate, cold finger, residual gas analyzer

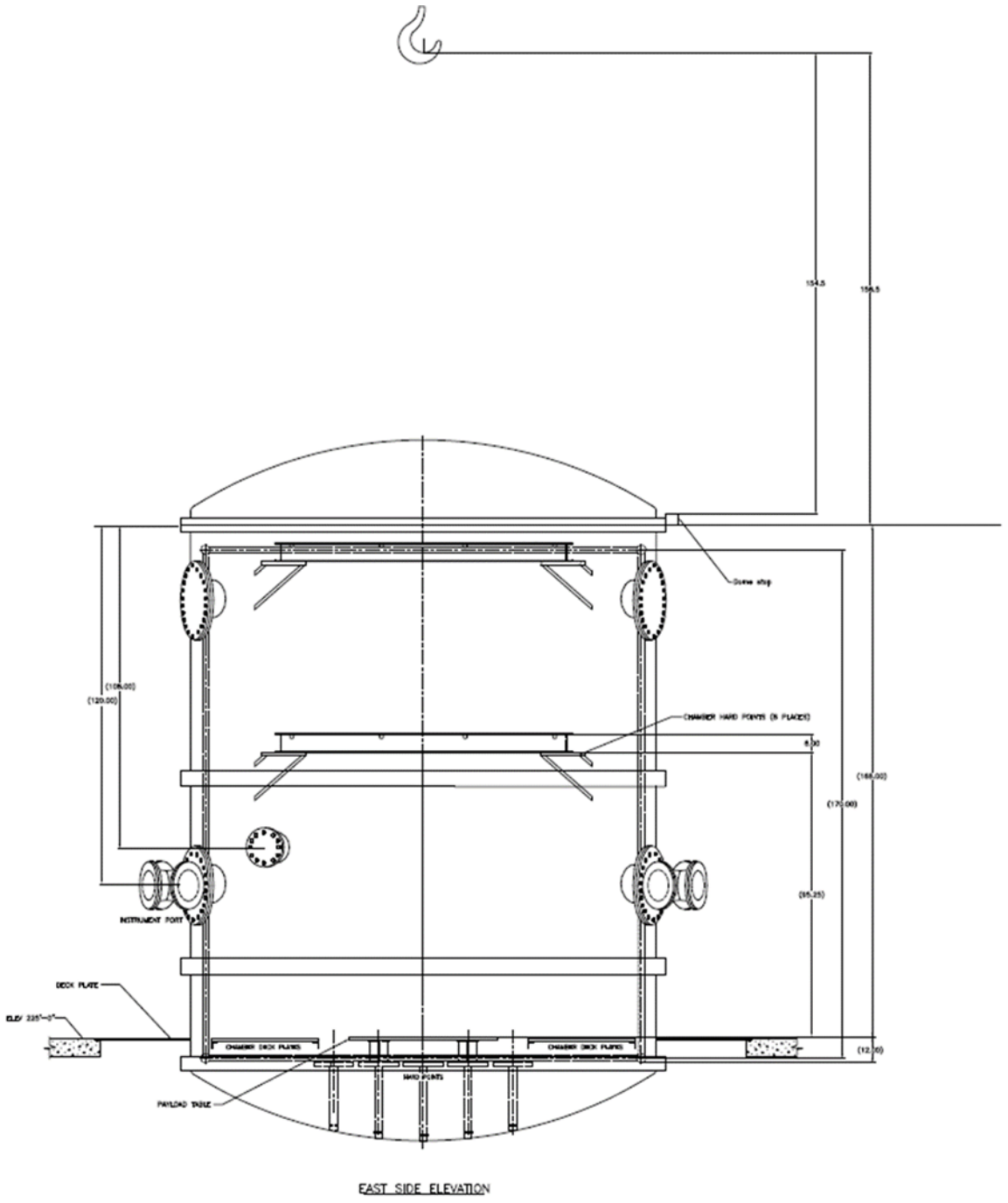
Auxiliary Equipment: Heater racks and thermal conditioning units (TCUs) are available to control auxiliary heater panels, cry-panels, and baseplates.



Facility 238 Chamber and Vacuum Schematic



Facility 238



Facility 238 Relevant Hook Dimensions

1.3.2.4 Facility 239 – 2.1 m x 2.4 m (7’ x 8’) Cryo-Pumped Vacuum Chamber

Description: This is a horizontal loading thermal vacuum test chamber. An overhead rail is available for mounting purposes and stainless-steel tubes are available for hanging thermal blankets. The facility is used for thermal vacuum and thermal balance testing and baking out test items. A clean tent at the chamber entrance provides class 10,000 cleanliness conditions.

Mode of Operation: The test item is craned, or hand carried onto the payload cart positioned at the chamber door. Typically, the payload is instrumented and connected to GSE prior to rolling it into the chamber. Ground support equipment cabling is connected through the penetration plates and ambient functional checks are performed. Access to the chamber is through a clean tent. The use of cleanroom procedures and the wearing of clean garments are **required when working in the chamber.**

Parameters:

Test Pressure:	<1 x 10^{-5} Torr (<2x10^{-7} psi)
Shroud Temperature:	
GN2 Mode:	-148°C to +117°C (125°K to +390°K)
LN2 Mode:	-190°C (83°K)
Cryopump Speed for N2:	30,000 l/s (63,560 cfm)

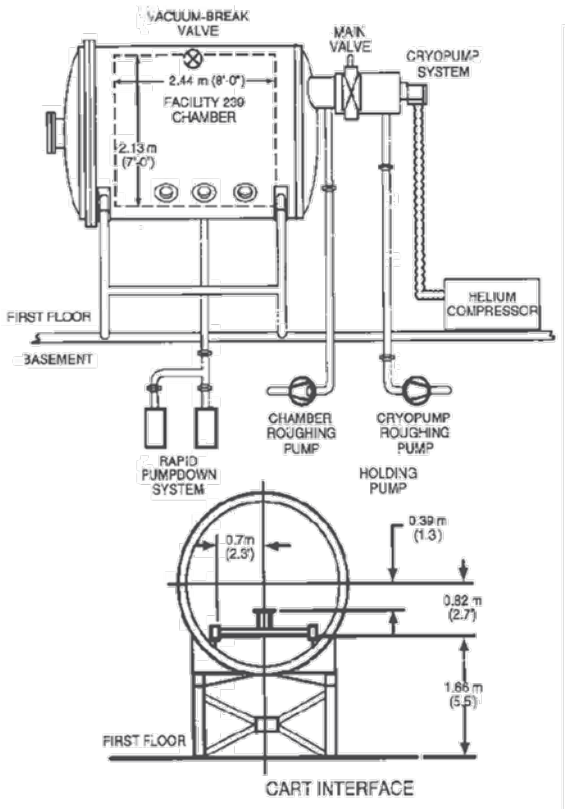
Physical Characteristics:

Test Volume:	2.13 m diameter x 2.44 m L (7’ x 8’)
Payload Support:	44” x 76” cart – 584 kg (1288 lb) capacity
	43.5” x 80” cart – 729 kg (1607 lb) capacity
Crane Capacity:	4,536 kg (5 Ton)
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

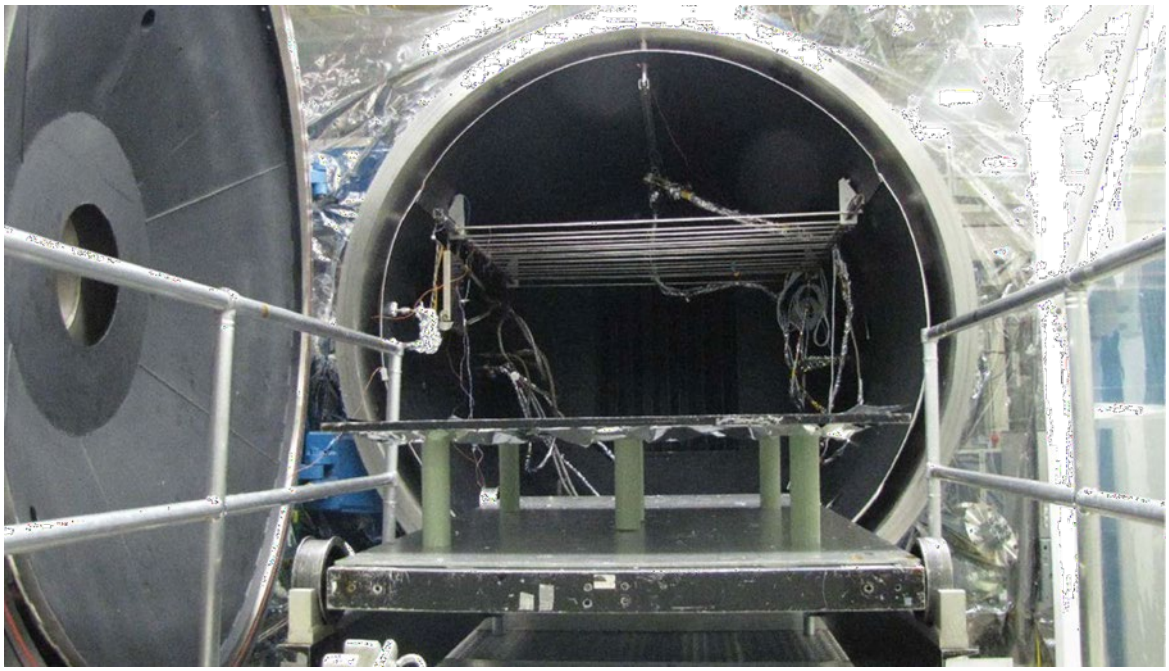
Integral Instrumentation:

Pressure:	Convectron – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauger – 10^{-3} Torr to ultimate
Payload Temperature:	126 channels
Contamination Monitors:	TQCM, cold finger, scavenger plate, residual gas analyzer

Auxiliary Equipment: Heater racks and thermal conditioning units (TCUs) are available to control auxiliary heater panels, cryo-panels, and baseplates.



Facility 239 Chamber and Vacuum Schematic



Facility 239

1.3.2.5 Facility 240 – 0.9 m x 0.9 m (3' x 3') Diffusion-Pumped Vacuum Chamber

Description: This diffusion-pumped facility is a horizontal loading thermal vacuum test chamber used for thermal vacuum testing and bakeout of test articles. The payload is mounted on a plate which is supported by rails welded to the chamber wall.

Mode of Operation: After the test article is instrumented with thermocouples and placed in the chamber, ground support equipment cabling is connected through the penetration plates, and ambient functional checks are performed. Placing the test article on a baseplate or suspending it from the overhead rail is an acceptable mounting method. Chamber evacuation is provided by rotary piston mechanical pumps and an oil diffusion pump. A main valve allows test set up while the pumping system is being established.

Parameters:

Test Pressure:	<1 x 10^{-5} Torr (<2x10^{-7} psi)
Shroud Temperature:	-107°C to + 116°C (166°K to 389°K)
Pumping Speed for N2:	1,600 L/sec (3,400 cfm)

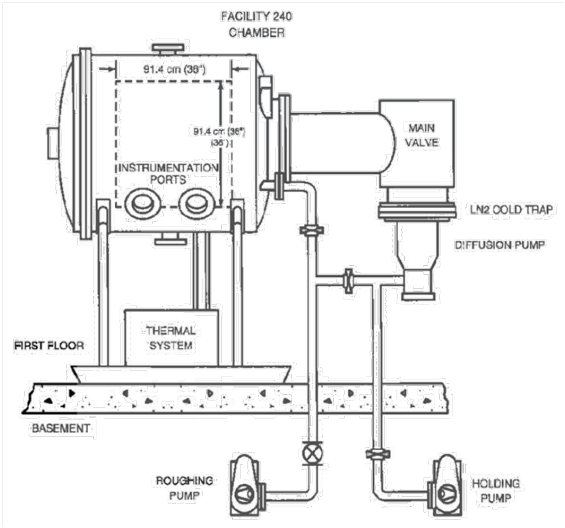
Physical Characteristics:

Test Volume:	0.91 m D x 0.91 m L (3' x 3')
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF
Max P/L weight:	840 kg (1854 lbs)

Integral Instrumentation:

Pressure:	Convectron – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	36 channels
Contamination Monitors:	TQCM, cold finger, scavenger plate

Auxiliary Equipment: Portable thermal systems are available to control baseplates, the thermoelectric quartz crystal microbalance (TQCM), and contamination control mirrors.



Facility 240 Chamber and Vacuum Schematic



Facility 240

1.3.2.6 Facility 241 – 0.9 m x 1.2 m (3' x 4') Cryo-Pumped Vacuum Chamber

Description: This cryo-pumped facility is a horizontal loading thermal vacuum chamber used for thermal vacuum testing and bakeout of test articles. The payload is mounted on a plate which is supported by rails welded to the chamber wall. The chamber platen consists of a ¼" – 20-hole patterns and is actively cooled alongside the shroud.

Mode of Operation: After the test article is instrumented and installed in the chamber, it is connected to the ground support equipment and data acquisition system via electrical feedthrough. After roughing down the chamber with the mechanical pump, ultimate pressure is achieved with a cryopump. A main valve allows test set up while the pumping system is being established.

Parameters:

Test Pressure:	<1 x 10^{-5} Torr (<2x10^{-7} psi)
Shroud Temperature:	
GN2 Mode:	-160°C to +150°C (113°K to 423°K)
Pumping Speed for N2:	1,500 L/sec (3,200 cfm)

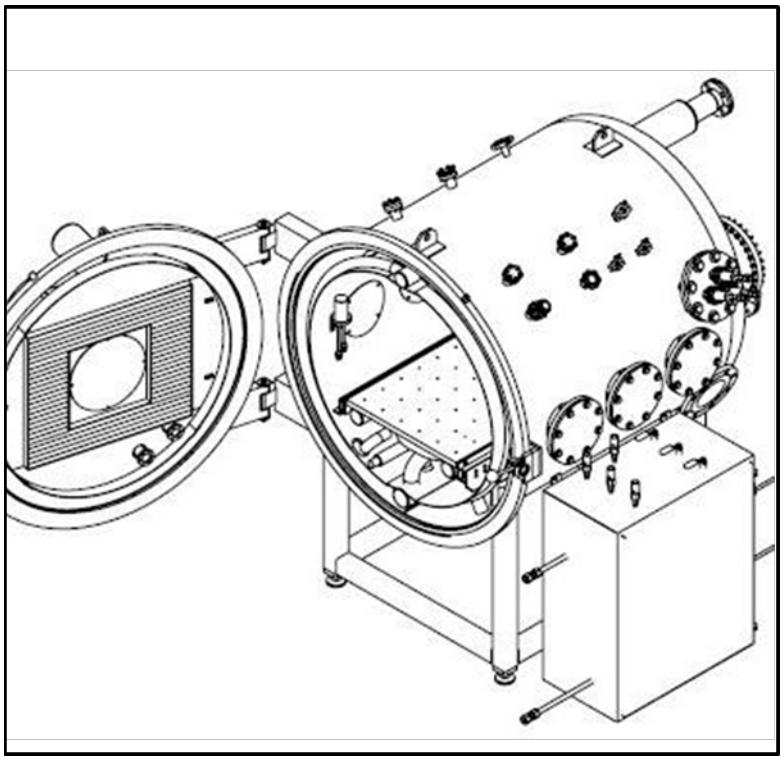
Physical Characteristics:

Test Volume:	0.91m diameter x 1.22m L (3' x 4')
Payload Support:	Platen on support rails, ¼" – 20-hole pattern
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

Integral Instrumentation:

Pressure:	T/C Gauge – Atm to 0.13 Pa (10^{-3} Torr)
	Convectron – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	72 channels
Contamination Monitor:	TQCM, cold finger, scavenger plate

Auxiliary Equipment: Portable thermal systems are available to control base plates, the thermoelectric quartz crystal microbalance (TQCM), and contamination mirrors.



Facility 241 Chamber Schematic



Facility 241

1.3.2.7 Facility 245 – 0.6 m x 0.9 m (2' x 3') Vacuum Chamber

Description: This turbo pumped facility is a horizontal loading thermal vacuum chamber used for bakeout of test articles. The vacuum chamber is a horizontal stainless-steel cylinder 2 feet in diameter by 3 feet deep. The side and rear shroud assembly rests on rails welded to the chamber walls. The door shroud is hinged to the main circular side shroud. The shrouds of this facility are made of black anodized aluminum sheet. 500-watt metal strip heaters are mounted to the backside of the shroud and controlled by Lambda heater power supplies. The chamber does not provide a method to cool the shrouds.

Mode of Operation: After the test article is instrumented with thermocouples and placed in the chamber, ground support equipment cabling is connected through the penetration plate, and ambient functional checks are performed. After roughing down the chamber with the rotary vane mechanical pump, ultimate pressure is achieved with the turbopump. Ports for payload electrical feedthroughs and liquid/gas feedthroughs are located on the west side of the chamber. The vacuum system is comprised of one mechanical pump and a 12" diameter turbopump.

Parameters:

Test Pressure:	<1 x 10^{-5} Torr (<2x10^{-7} psi)
Shroud Temperature:	+22°C to +150°C (295°K to 423°K)
Pumping Speed for N2:	1,500 L/sec (3,200 cfm)

Physical Characteristics:

Test Volume:	0.61 m diameter x 0.91 m L (2' x 3')
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF
Max P/L weight:	90kg (200 lbs)

Integral Instrumentation:

Pressure:	Convectron – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	18 channels
Contamination Monitor:	TQCM, cold finger

Auxiliary Equipment: Portable thermal systems are available to control base plates, thermoelectric quartz crystal microbalance (TQCM), and contamination mirrors.



Facility 245

1.3.2.8 Facility 246 – 1.2 m x 1.8 m (4' x 6') Thermal Vacuum Chamber

Description: This is a horizontal loading thermal vacuum test chamber used to simulate lunar vacuum environments. Electrical feedthroughs and liquid and gas penetrations are provided at locations on the rear section of the chamber.

Mode of Operation: Test items are loaded onto a 30" wide x 50" deep payload table that can support 227 kg (500 lb). Chamber evacuation is provided first by a mechanical roughing pump, followed by a cryopump. Shroud temperature conditioning is accomplished by a recirculating GN2 thermal system.

Parameters:

Test Pressure:	$<1x10^{-5}$ Torr ($<2x10^{-7}$ psi)
Shroud Temperature:	
GN2 Mode:	-140°C to 150°C (133°K to 423°K)

Physical Characteristics:

Test Volume:	1.06 m dia x 1.68 m L (3.5' x 5.5')
Payload Support:	227 kg (500 lb.)
Instrumentation Ports:	12 Each 15.2 cm dia (6"), 2 each 20.3 cm dia (8"), 4 each 25.4 cm dia (10"), 1 each 35.6cm dia (14")
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF

Integral Instrumentation:

Pressure:	Convectron – Atm to 10^{-3} Torr Ion Gauge – 10^{-3} Torr to ultimate
Contamination Monitors:	Cold Finger, scavenger plate

Auxiliary Equipment: Portable thermal systems are available to control baseplates and contamination control mirrors.



Facility 246 South-Side View



Facility 246 North-Side View

1.3.2.9 Facility 281 – 0.9 m x 1.2 m (3' x 4') Cryo-Pumped Vacuum Chamber

Description: This cryo-pumped facility is a horizontal loading thermal vacuum chamber used for thermal vacuum testing and baking out test articles. The payload is mounted on a plate which is attached to rails in the chamber.

Mode of Operation: After the test article is instrumented and installed in the chamber, it is connected to the ground support equipment and data acquisition system via electrical feedthroughs. After roughing down the chamber with the mechanical pump, ultimate pressure is achieved with a cryopump. A main valve allows test set up while the pumping system is being established.

Parameters:

Test Pressure:	<1 x 10^{-5} Torr (<2x10^{-7} psi)
Shroud Temperature:	
GN2 Mode:	-140°C to +150°C (133°K to 423°K)
LN2 Mode:	-190°C (83°K)
Pumping Speed for N2:	1,500 L/sec (3,200 cfm)

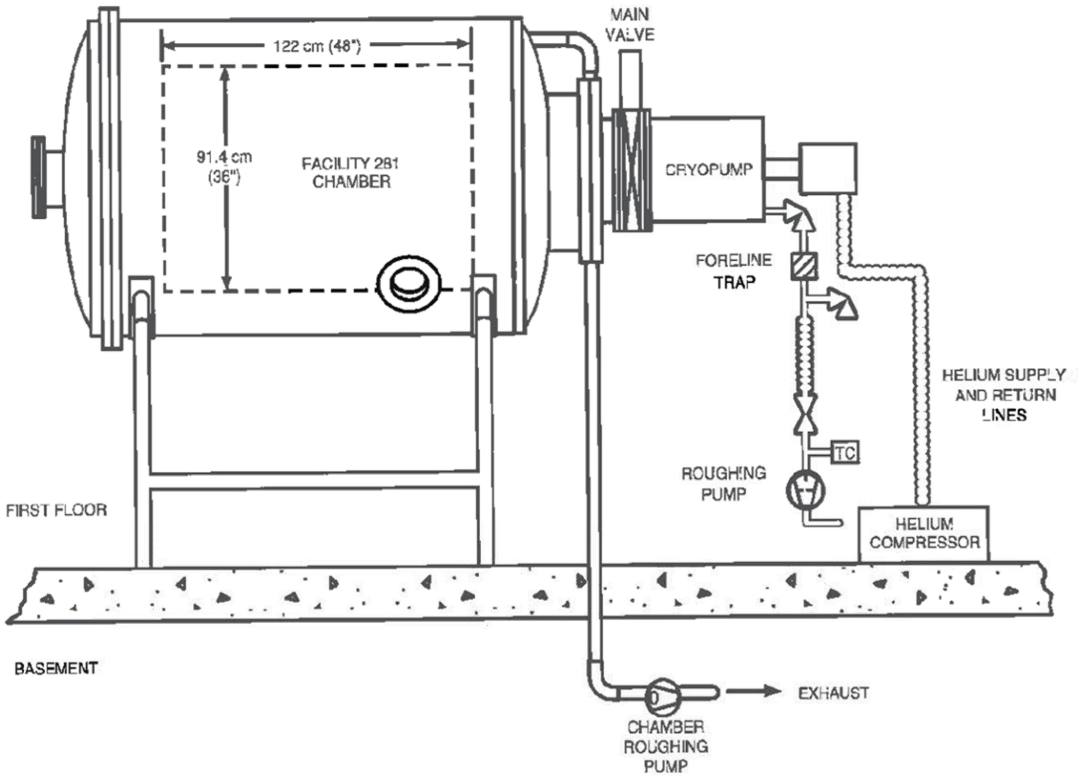
Physical Characteristics:

Test Volume:	0.91m diameter x 1.22 m L (3' x 4')
Payload Support:	Plate on support rails
Std. Electrical Feedthroughs:	61-pin, 37-pin, 7-pin,4-pin, RF

Integral Instrumentation:

Pressure:	T/C Gauge – Atm to 0.13 Pa (10^{-3} Torr)
	Convectron – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauge – 10^{-3} Torr to ultimate
Payload Temperature:	72 channels
Contamination Monitor:	TQCM, cold finger, scavenger plate

Auxiliary Equipment: Portable Thermal systems are available to control base plates, the thermoelectric quartz crystal microbalance (TQCM), and contamination mirrors.



Facility 281 Chamber and Vacuum Schematic



Facility 281

1.3.2.10 Facility 290 – 8.2 m x 12.2 m (27' x 40') Cryo-Pumped Vacuum Chamber

Description: Facility 290, also known as the Space Environment Simulator (SES), is a very large vertical loading thermal vacuum chamber capable of achieving ultra-low pressure and a wide range of thermal conditions. In addition to the 27'D x 40'H nitrogen shroud, a 1 kW at 20K helium refrigerator can be used to cool a helium shroud and/or other auxiliary equipment. An integrated HEPA filtration system provides a Class 10,000 environment in the chamber and anteroom. The chamber is used for thermal vacuum and thermal balance testing and baking out very large test articles.

Load Capacities: Load Analysis has been performed to verify that:

- The chamber payload table has a safe working load of 40,000 lbs.
- The chamber floor shroud has a safe working load of 2,585 lbs.
- The personnel grates are pie-shaped stainless-steel wedges that are installed above the floor shroud and are supported by hard points on the outer diameter and the payload table on the inner diameter. Installed optionally, they can support up to 100 pounds per square foot.

Please consult Code 549 Space Simulation Test Engineer early on in your planning process to verify that your payload and GSE can be supported by the chamber.

Mode of Operation: To load large test articles the chamber dome is rolled back to allow loading with the overhead crane. Small test articles and equipment are brought in through the personnel entrance located in the basement. Wearing of clean garments is required. Entry to instrument the payload, connect ground support equipment cabling, and install hardware is through a cleanroom air shower at the personnel door. Scaffolding may be erected to provide access to the payload. An area adjacent to the main facility control console is reserved for the experimenter's ground support equipment.

Chamber evacuation is provided by eight rotary piston mechanical pumps with Roots blowers, seven cryopumps and three turbomolecular pumps. Under normal operation, four cryopumps are used and the remaining three are online and available as backups if needed. Thermal control is provided by an aluminum tube-in-sheet cylindrical shroud with both liquid nitrogen and gaseous nitrogen operational modes. The dome and bottom shrouds are also connected to the thermal skid. The payload table can also be plumbed into the thermal system or controlled with a TCU. Resistance heater arrays and gaseous nitrogen panels are available for special thermal requirements. Thermoelectric quartz crystal microbalances (TQCMs) and a residual gas analyzer (RGA) provide both quantitative and qualitative monitoring of molecular contamination and gaseous constituents within the chamber. Camera systems are available for monitoring the test article.

Helium Skid: A 1.0 kW helium refrigeration system is piped to 2.54 cm (1") VCR fittings inside the chamber that may be connected to manifolds providing the capability of achieving 20K on those surfaces. This is enough cooling energy to cool and maintain large thermal shrouds at cryogenic temperatures.

Parameters:

Test Pressure:	13.3 µPa (10^{-7} Torr)
Shroud Temperature:	
GN2 Mode:	-80°C to +80°C (193°K to 353°K)
LN2 Mode:	-180°C (93°K)
Chamber Pumping Speed:	
7 cryopumps:	2.1 x 10^5 L/sec (4.5 x 10^5 cfm) @ 133 µPa (10^{-6} Torr)
3 Turbomolecular Pumps:	6,000 L/sec (12,700 cfm) @ 133 µPa (10^{-6} Torr)

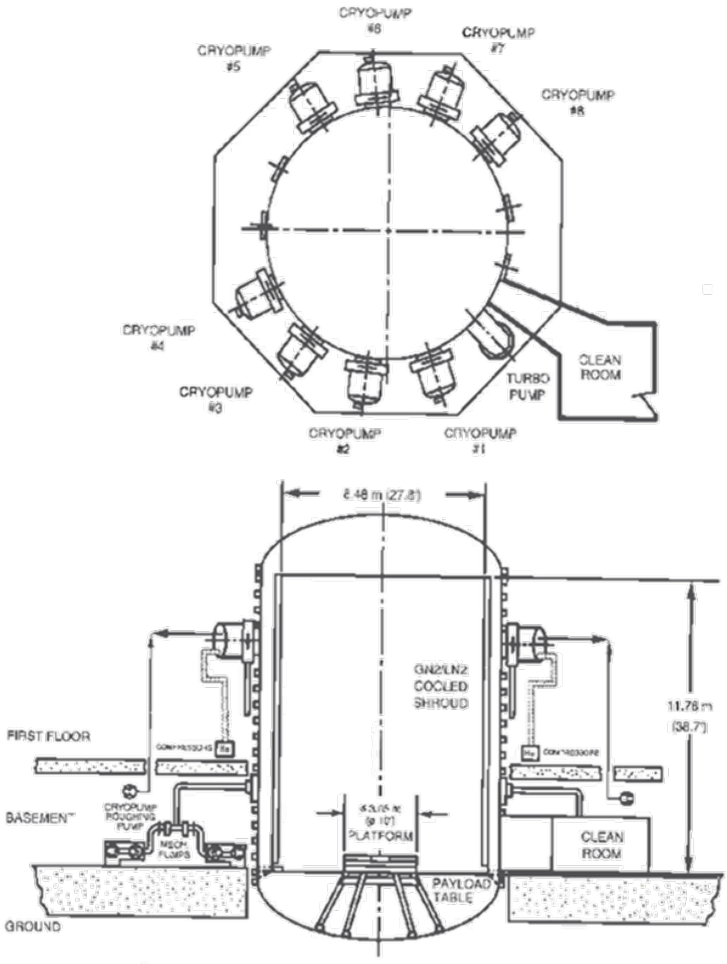
Physical Characteristics:

Test Volume:	8.23 m diameter x 12.19 m H (27' x 40')
Payload Table Capacity:	11794 kg (26000 lb)
Standard Electrical Feedthroughs:	61-pin, 37-pin, 7-pin, 4-pin, RF
Personnel Door:	1.8 m H x 1.5 m H (6' H x 5'W)
Crane Capacity:	13,608 (15 Ton)
Crane Hook Height:	12.8 m (42') to I-Beam Structure

Integral Instrumentation:

Pressure:	Convectron (2) – Atm to 0.13 Pa (10^{-3} Torr)
	Ion Gauge (3) 0.13 Pa to 13.3 µPa (10^{-3} to 10^{-7} Torr)
Payload Temperature:	760 channels of thermocouples
Contamination Monitor:	TQCM, cold finger, scavenger plate, residual gas analyzer
TQCM frequencies:	15 MHz (4)

Auxiliary Equipment: Portable thermal systems are available to control base plates, the payload table, the thermoelectric quartz crystal microbalances (TQCMs), and contamination mirrors.



Facility 290 Chamber and Vacuum Schematic



Facility 290

1.3.3 Thermal Vacuum Data Acquisition Facility

Description: This facility is a client/server Windows network application operating over a local area network (LAN). It is designed to measure, display, and store data such as temperature, chamber pressure, thermoelectric quartz crystal microbalance (TQCM) frequencies, voltages, and other chamber and payload data.

Mode of Operation: Data is acquired by the Supervisory Control and Data Acquisition (SCADA) computer every minute and recorded in the thermal vacuum Oracle database located on the server. Data stations located throughout Labs 7 and 10 can view this data through an Ethernet TCP/IP connection. The Thermal/Vacuum Data System (TVDS) graphical user interface (GUI) displays the data in tabular and graphical formats.

The number and location of payload thermocouples are determined by the experimenter/thermal engineer. Facility thermocouples are strategically placed to provide a full representation of all chamber shrouds. The different operating parameters (Temperature, pressure, TQCM frequencies, and rate of TQCM change can be viewed simultaneously in tabular format or graphical plot. All measuring devices have alarm limits that allow for facility and payload control.

All recorded data and data station configurations are stored in an Oracle database. An uninterruptible power supply prevents the loss of data in case of a power outage. Data is backed up at the end of every test.

Software features: The TVDS application runs on each data station and can be customized by the operator or experimenter. Any facility that is active (under test) can be viewed on any data station.

Operators can create, start, and stop tests, enable/disable measuring devices, and edit alarm limits, averages, and gradients. Display options include tabular displays, graphical plot displays, multiple color schemes, scale-able plots, and copying displays from other data stations. All tabular and plot displays can be printed to a LAN printer.



Thermal Vacuum Data Acquisition Area

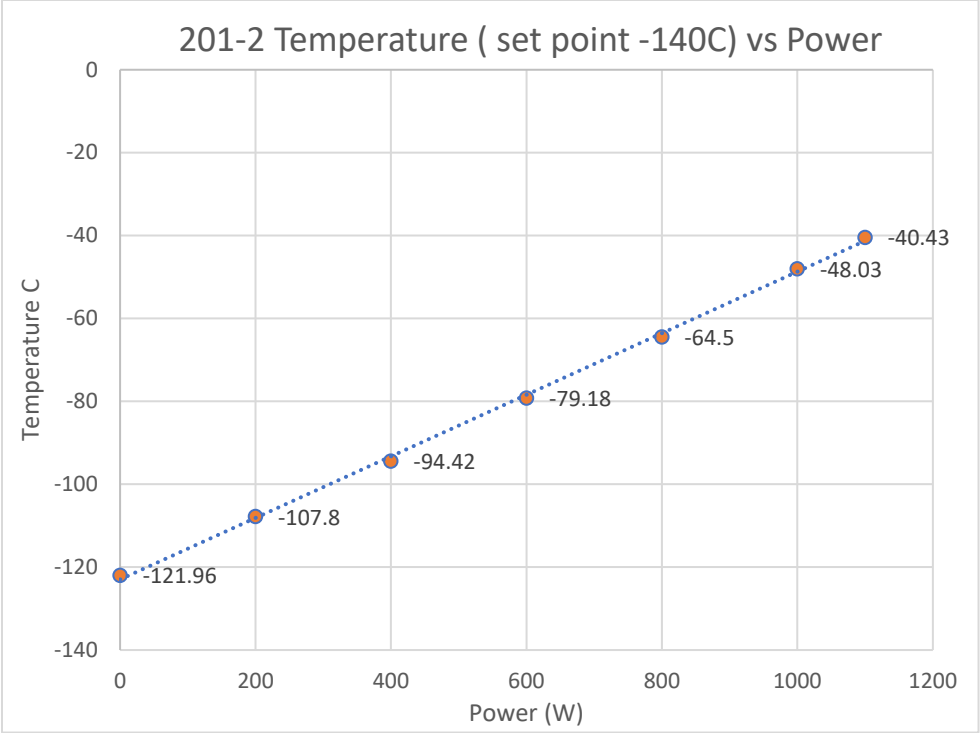
1.3.4 Thermal Conditioning Units

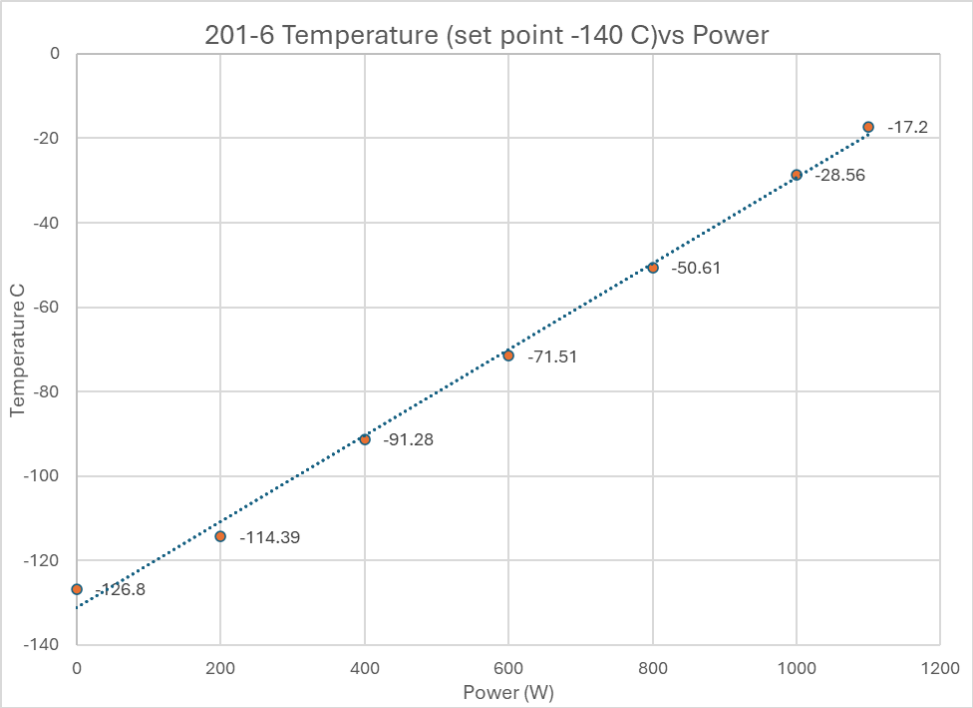
Description: The following thermal conditioning units are portable and available for use at each thermal vacuum facility as needed. They are designed to produce and maintain a wide range of temperatures. The heat transfer medium is GN_2 for all units. Typical applications for these units include independent thermal control of test articles and contamination monitoring devices such as mirrors and TQCMs. Chamber penetrations are configured to accommodate the thermal conditioning units. Images of each TCU are included below, along with graphs of their performance at their lowest setpoint, with a 2' x 2' cold plate and a heat load applied.

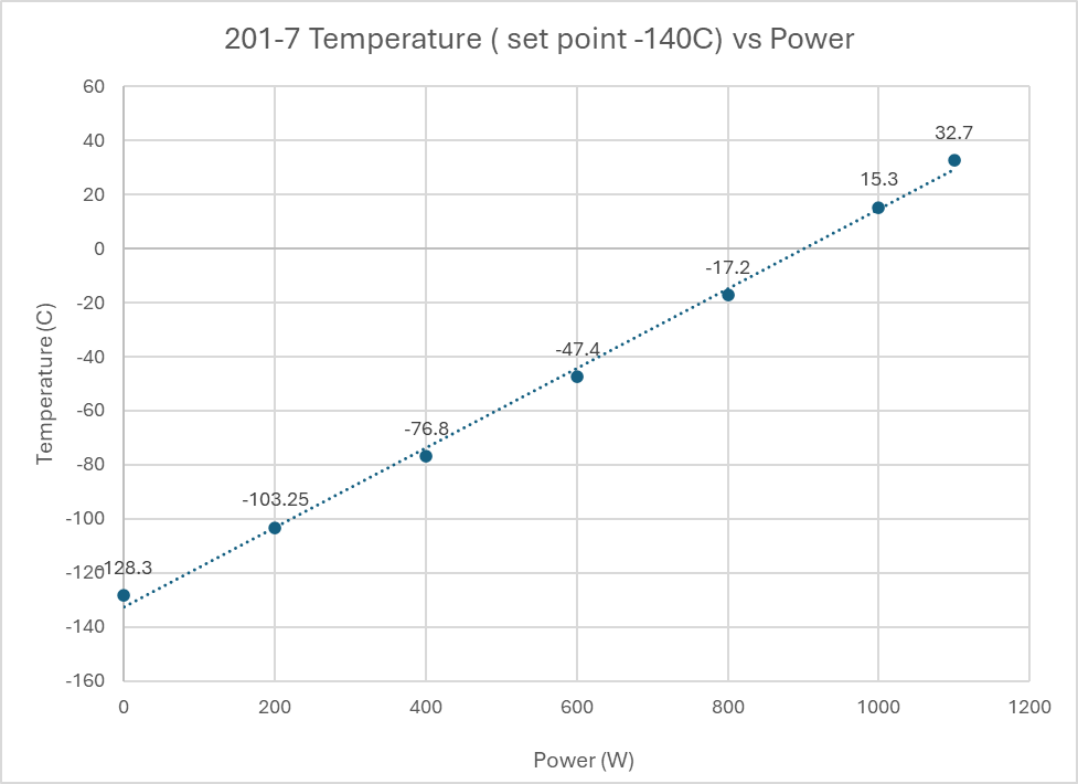
Facility No.	Temp Range	Cooling Cap. (Watt)	Size (H x W x D)	MFR
201	-140 to 140°C (133 to 413°K)	1,000	1.8 m x 0.97 m x 1.7 m (5.9' x 3.2' x 5.6')	CVI (201-1 through 201-5) XL (201-6) Dynavac (201-7)
202	-120 to 150°C (153 to 423°K)	500	1.3 m x 0.63 m x 0.63 m (4.3' x 2.1' x 2.1')	Built In-House
203	-140 to 140°C (133 to 413°K)	500	0.40 m x 0.55 m x 0.34 m (1.3' x 1.8' x 1.1')	Built In-House
205	-100 to 100°C (173 to 373°K)	500	0.89 m x 0.51 m x 0.51 m (2.9' x 1.7' x 1.7')	Slack



Facility 201

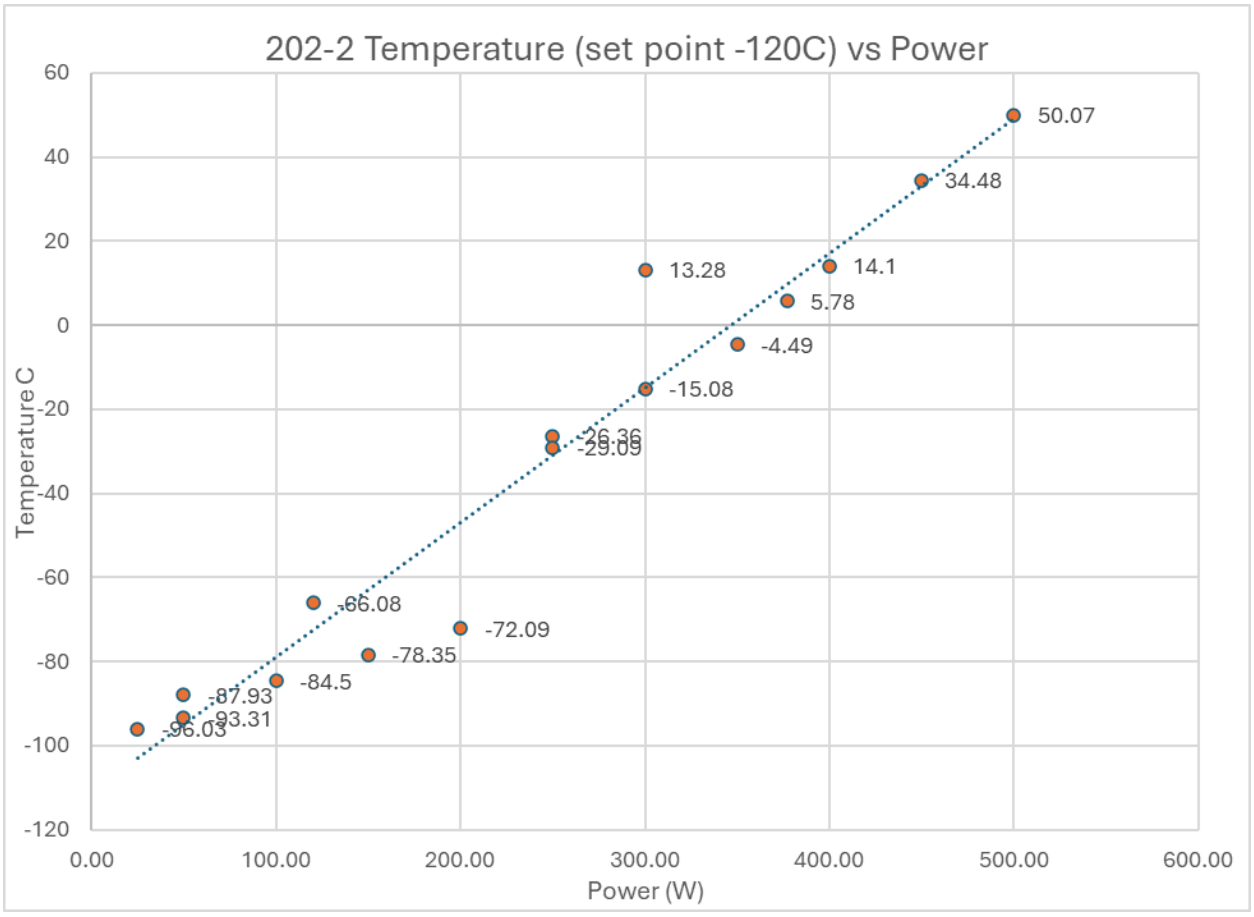

201-2 Temperature (set point -140C) vs Power
Temperature C
Power (W)
0
-20
-40
-60
-80
-100
-120
-140
0
200
400
600
800
1000
1200
-121.96
-107.8
-94.42
-79.18
-64.5
-48.03
-40.43


201-6 Temperature (set point -140 C)vs Power
Temperature C
Power (W)
0
-20
-40
-60
-80
-100
-120
-140
0
200
400
600
800
1000
1200
-126.8
-114.39
-91.28
-71.51
-50.61
-28.56
-17.2


201-7 Temperature (set point -140C) vs Power
Temperature (C)
Power (W)
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
0
200
400
600
800
1000
1200
-128.3
-103.25
-76.8
-47.4
-17.2
15.3
32.7

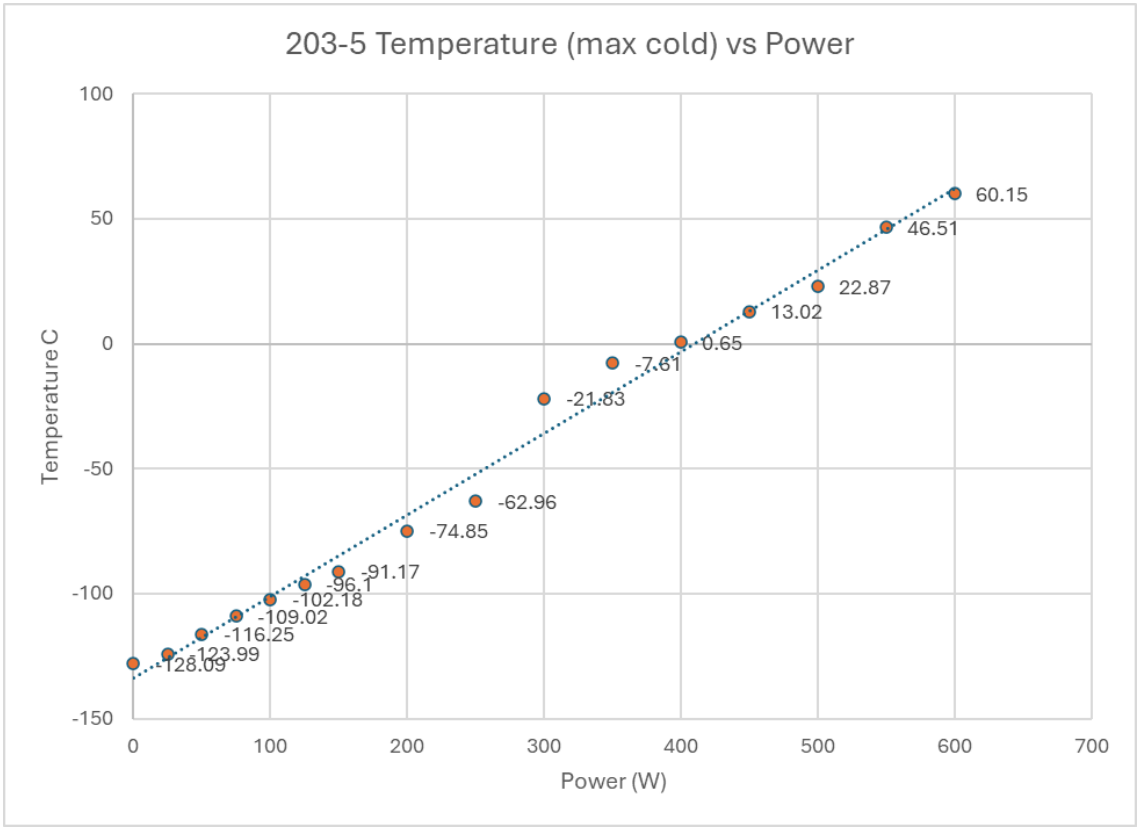


Facility 202





Facility 203





Facility 205

1.3.5 Automated Electric Heater Controller (Facility 315)

Description: This system can control up to twelve heater circuits, each of which can be in temperature controlled or constant power mode, as desired. Four of the circuits can be in zero-Q mode. The rack contains twelve direct current power supplies, a programmable logic controller (PLC), a touch screen operator interface, and a Modbus Plus communication port. The system uses the proportional plus integral plus derivative (PID) control strategy.

Mode of Operation: The heater system can be operated at the touch screen or remotely via Modbus Plus from a desktop computer. For each circuit, the user enters the mode, set point, temperature limit, heater current limit, and the heater resistance. The PLC then controls the amount of continuous (i.e., not pulsed) current to the heater to achieve the desired temperature or power level. Temperatures and power levels (in any mode) are stored in the thermal vacuum data system.

Parameters:

Temperature:	-200°C to +100°C (73°K to 373°K) with Kapton Strip Heaters, -200°C to +600°C (73°K to 873°K) with Calrods
Heater Zones:	12 channels
Heater Power:	600 Watts per channel (0-150 VDC @ 0-4 A)
Modes:	Temperature controlled, constant power, zero-Q
Temperature Sensors:	Type T or K thermocouples, Platinum Resistance Thermometers (PRTs)

Physical Characteristics:

Portable Unit:	2.06 m H x 0.56 m W x 0.76 m D (6.75' x 1.8' x 2.5')



315 Automated Heater Controller

1.3.6 Automated Electric Heater Controller (Facility 316)

Description: This system can control up to twelve heater circuits, each of which can be in temperature controlled or constant power mode, as desired. Four of the circuits can be in zero-Q mode. The rack contains twelve direct current power supplies, a programmable logic controller (PLC), a touch screen operator interface, and a ModBus Plus communication port. The system uses the proportional plus integral plus derivative (PID) control strategy.

Mode of Operation: The heater system can be operated at the touch screen or remotely via ModBus Plus from a desktop computer. For each circuit, the user enters the mode, set point, temperature limit, heater current limit, and the heater resistance. The PLC then controls the amount of continuous (i.e., not pulsed) current to the heater to achieve the desired temperature or power level. Temperatures and power levels (in any mode) are stored in the thermal vacuum data system.

Parameters:

Temperature:	-200°C to +100°C (73°K to 373°K) with Kapton Strip Heaters, -200°C to +600°C (73°K to 873°K) with Calrods
Heater Zones:	12 channels
Heater Power:	600 Watts per channel (0-150 VDC @ 0-12 A)
Modes:	Temperature controlled, constant power, zero-Q
Temperature Sensors:	Type T or K thermocouples, Platinum Resistance Thermometers (PRTs)

Physical Characteristics:

Portable Unit:	2.06 m H x 0.56 m W x 0.76 m D (6.75' x 1.8' x 2.5')



316 Automated Heater Controller

1.3.7 Rapid Pump-Down System (Facility 208)

Description: This high-speed vacuum pump-down system is comprised of two rotary piston pumps manifolded in parallel to a chamber exhaust line. Two 2.1 m x 2.4 m (7' x 8') thermal vacuum chambers (one diffusion pumped, one cryo-pumped) are manifolded in parallel to the exhaust line providing rapid pump-down. There is a fore line valve at the inlet of each pump, and a shut-off valve at each chamber. The pumps and valves are in the basement and operated from a remote console.

Mode of Operation: Each pump is started, and its ultimate pressure is verified to be less than 2.66 Pa (2 x 10^{-2} Torr). The foreline valve and the valve at the required chamber are opened. When test pressure is achieved, the chamber valve is closed. The foreline valves are closed and the pumps are secured.

Parameters:

Ultimate Pressure:	1.33 Pa (10^{-2} Torr)
Pump Down Time:	Either chamber – Atm to 2.66 Pa (2 x 10^{-2} Torr) in 5 min.
Pump Speed:	22 m^3/min (780 ft^3/min) each pump

Physical Characteristics:

Foreline Size:	25 cm (10") diameter
Chamber Manifold:	31 cm (12") diameter

Integral Instrumentation:

Pump Foreline Pressure:	T/C Gauge for Atm to 0.13 Pa (10^{-3} Torr)



Rapid Pump-Down System

1.3.8 Contamination Monitoring

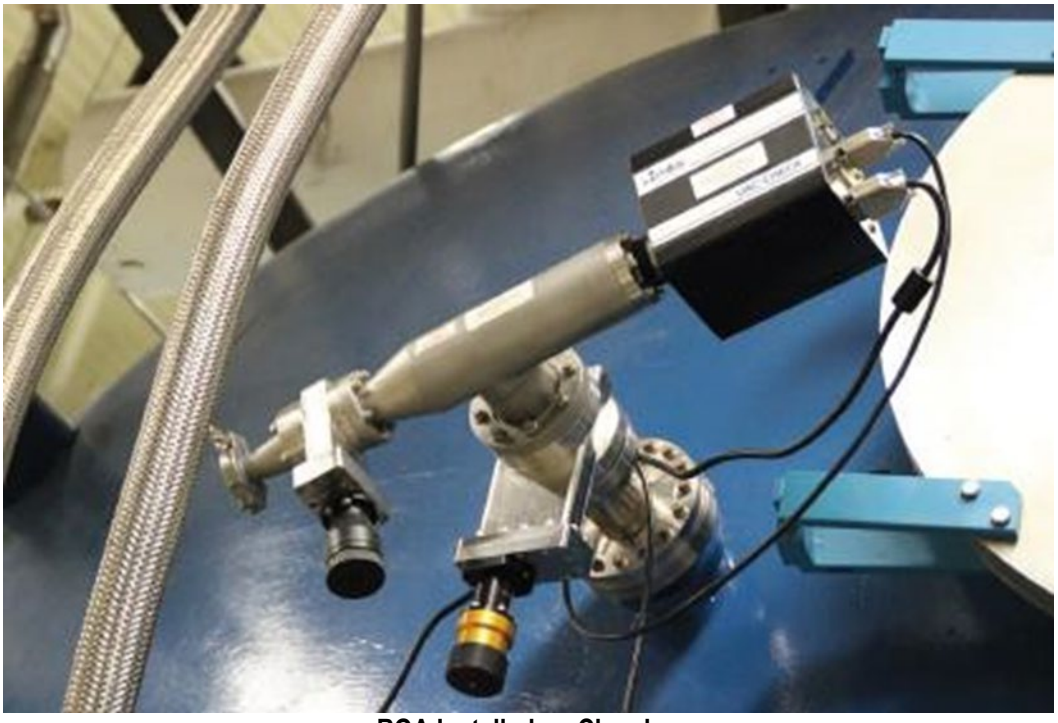
1.3.8.1 Residual Gas Analyzer

Description: The residual gas analyzer is used to measure the partial pressures of ionized molecules over a mass range of 1 to 200 atomic mass units (AMU). Using a combined RF and electrostatic field formed by two metal rods, the RGA scans the mass range and detects the partial of each element or compound fraction.

Mode of Operation: The RGA probe is in the thermal vacuum facility and is oriented to maximize the detection of the outgassing species. After the facility pressure reaches 13.3 mPa (10^{-4} Torr), the instrument may be activated. An alternate technique is to use the micro sampling valve at high chamber pressure. Monitoring and recording of the vacuum environment is via a display meter and printer.

Note: Two auxiliary RGA manifolds are available, with appropriate valves, that provide sampling of chamber gasses when chamber pressure is between 13.3 mPa (10^{-4} Torr) and atmosphere.

Make & Model	Faraday Cup	Electron Multiplier	AMU Range	Max. Operating Pressure	Min. Detectable Partial Pressure
MKS PPT-200EM	Yes	Yes	1-200	13.3 mPa (1.0×10^{-4} Torr)	6.7×10^{-12} Pa (50×10^{-14} Torr)



RGA Installed on Chamber

1.3.8.2 Thermoelectric Quartz Crystal Microbalance

Description: The thermoelectric quartz crystal microbalance (TQCM) and control unit system measures and records condensable masses which deposit on a piezoelectric crystal. Extreme accuracy is obtained by comparing the exposed measurement crystal to a matched encapsulated reference crystal located in the same TQCM head. A computer controlled thermoelectric pump provides a high degree of crystal temperature control, which is vital for accurate frequency measurement. All relevant data is sent from the control unit and the PC control station to the thermal vacuum data system. Two models of TQCMs are available: the CrystalTek 57T 15 MHz TQCM with 66TR Controller, and the QCM Research Mark 10 15 MHz TQCM with Model 2000 Controller.

Mode of Operation: One or more TQCM sensing units are installed in a thermal vacuum chamber. The chamber is pumped down to a test pressure of 1.33 mPa (10^{-5} Torr) or less, at which point the TQCM is turned on and set for the appropriate operating temperature. As the payload outgasses and materials condense on the TQCM sensing crystal, the crystal frequency increases directly proportionally to the amount of payload outgassing.

Parameters:

Mass Sensitivity:	1.97 x 10^{-9} g/cm^2-Hz (0.45 x 10^{-9} oz/in^2-Hz) for the 15 MHz QCM Research Unit 1.96 x 10^{-9} g/cm^2-Hz (0.45 x 10^{-9} oz/in^2-Hz) for the 15 MHz CrystalTek Unit
Crystal Temperature:	-50° to +100°C, ± 0.1°C (223°K to + 373°K, ±0.1°K) for the QCM Research Unit -59° to +100°C, ± 0.1°C (214°K to + 373°K, ±0.5°K) for the CrystalTek Unit
Sensor Unit Size:	5 cm (2") diameter x 25.5 cm (10") L with heat sink lines

Integral Instrumentation: The instrument consists of a TQCM sensor head unit, M-2000 multichannel control unit or CrystalTek 66TR Controller, QCM Data Acquisition and Control workstation, and heat sink temperature control system.



CrystalTek 66TR Controller and QCM Research Model 2000 Controller

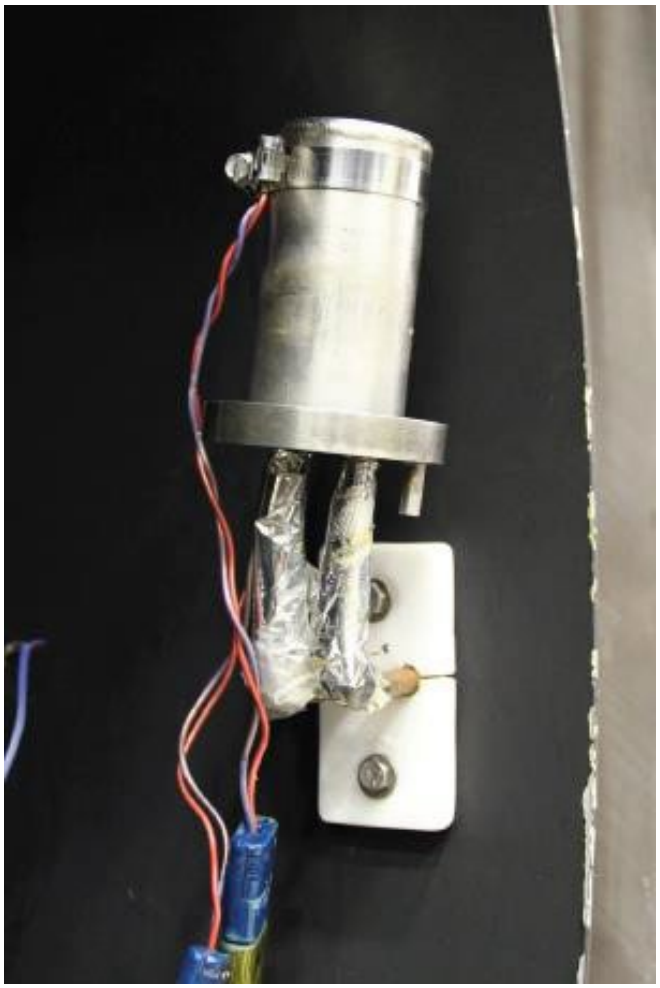
1.3.8.3 Cold Finger (C/F)

Description: Cold fingers are small stainless-steel cylinders which are mounted in the test volume of each thermal vacuum chamber. Condensable vapors are collected by the cold finger and analyzed after the test. In some cases, a large cold plate is used to collect the condensable materials. The cold finger is maintained at LN2 temperature during test and until the chamber is backfilled to 80 kPa (600 Torr).

Mode of Operation: The cold finger is thoroughly cleaned before the test. After the thermal vacuum test, the cold finger is warmed and rinsed with isopropyl alcohol. The rinse sample is collected in a clean bottle and sent to the Materials Assurance Branch for quantitative and qualitative analyses.

Parameters:

Size:	5cm (22”) diameter x 7.6 cm H (3”)
Surface Area:	142 cm^2 (22 in^2) nominal
Temperature:	-196°C (77°K)



C/F Installed Inside Chamber

1.3.8.4 Contamination Control Mirror

Description: These aluminum coated mirrors are used primarily to collect outgassed materials in the thermal vacuum chambers; however, they may be placed anywhere to collect condensable matter. To determine the quantity of material on the mirror, reflective ultraviolet measurements are made prior to test, and then compared to post-test measurements for a loss of reflectivity.

Mode of Operation: The mirror is placed in the thermal vacuum chamber (or other environment) and allowed to remain in that location for the duration of the test. In most cases, the mirror's temperature follows the thermal vacuum chamber temperature profile; however, the mirror's temperature can be controlled if desired. For large accretions (greater than 10% change in reflectivity) the mirror is sent to the Materials Assurance Branch for chemical analysis of the nonvolatile residue.

Parameters:

Temperature:	-190°C to +100°C (83°K to 373°K)
Measurement Error:	± 2%
Measurement Wavelength:	1216 Å, 1608 Å, and 2000 Å
Mirror Size:	5 cm x 5 cm (2" x 2"), coated on one side
Coating:	Al – 600 to 800 Å thick
Over Coating:	MgF1 - 250Å thick

1.3.8.5 Total Outgassing Measurement (TOM) Boxes

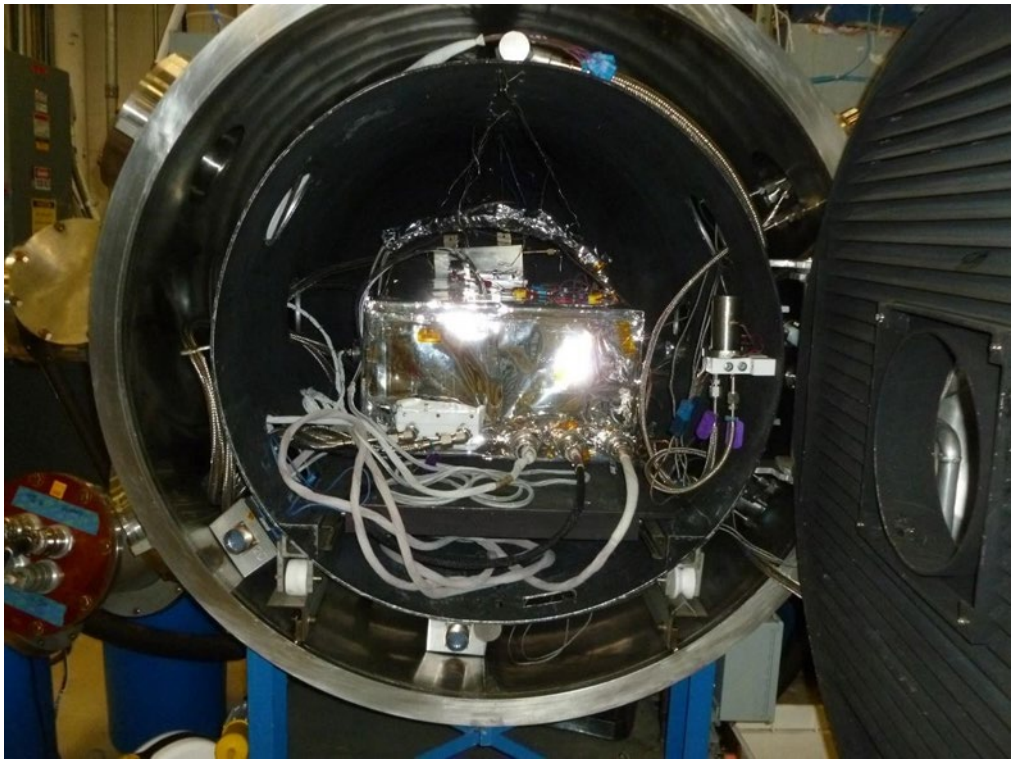
Description: A Total Source Outgassing Measurement (TOM) Box, also referred to as a Bakeout Box, is designed to extend the field of view of a TQCM to encompass the entire sample. Without the box, the TQCM may only capture the outgassing from a limited area of the payload. Thus, TOM boxes ultimately increase the accuracy of TQCM measurements during a bakeout. The TOM Box is designed to be used with relatively clean test articles in need of certification with a stringent of contamination criterion.

Physical Characteristics: A TOM Box is an anodized aluminum box with an outgassing vent of known size, a port for a TQCM, a cold finger, and independently controllable heater panels.

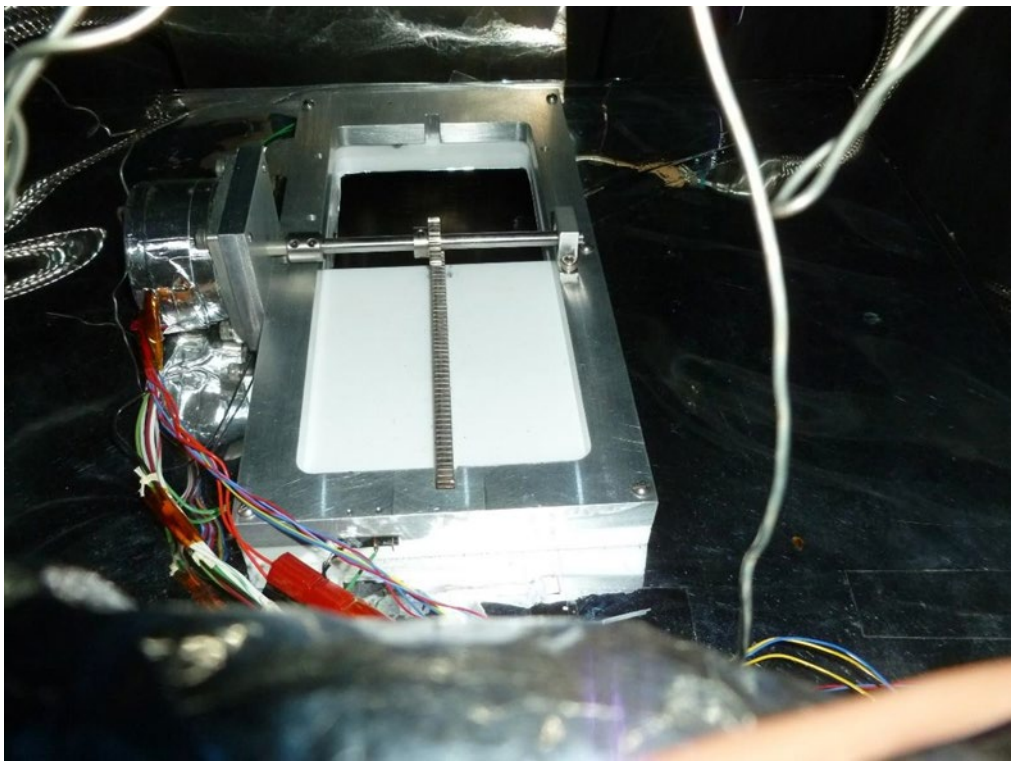
Mode of Operation: Prior to chamber certification, the TOM Box must be sealed such that outgassing will occur only through the designated vent. This is accomplished by placing Kapton tape along the edges of the box and by taping a piece of Kapton film around the TQCM. After the test articles have been installed, the lid to the TOM Box shall also be sealed with Kapton tape. If necessary, the box vent shall be restricted with Kapton or Mylar film. Through is designated port, the TQCM facing inside the box shall be used to determine whether test criteria are met.

During the payload bakeout phase, increasing the area available for outgassing reduces the time required to complete that phase of the test. In some boxes, the venting area can be increased by manually opening the cover of the box. A Remote Operated Shutter (ROS) system has been integrated into the remaining TOM box that allows the operators to fully/partially open and close a shutter on the cover of the box without opening the chamber.

Available TOM Boxes				
Box	**Size (W x L x H)**	**PTEs**	**Heater Ckts**	**Notes**
1	20” x 28” x 12”	13	6	
2	20” x 28” x 12”	14	7	ROS
5	24” x 78” x 24”	16	6	Coffin
6	22” x 32” x 14”	13	6	
GOES	24” x 24” x 12”	13	6	False Bottom



Box #2 Installed in Chamber



Box #2 Lid Shutter

2.0 INTEGRATION SERVICES AND FACILITIES

The Environmental Test Engineering and Integration Branch provides trained personnel and facilities necessary to support integration of flight hardware ranging from sub-assemblies to fully configured flight spacecraft. Integration services and facilities include mechanical integration support, electrical cable harness development, thermal blanket development, contamination control support, and cleanroom facilities.

The Environmental Test and Integration Branch's functions include the following integration disciplines:

Mechanical Integration:

Maintenance and Operation of Cleanrooms
Electrical and Mechanical Integration
Handling of Spacecraft
Functional Checks of Spacecraft Hardware
Field Support at Launch Sites and Remote Facilities

Thermal Blanket Facility:

Thermal Blanket Template Design
Thermal Blanket Fabrication
Thermal Blanket Installation
Launch Site Closeout and Support

Electrical Cable Harness Facility:

Cable Harness Fabrication
Continuity and Insulation Resistance Testing
Cable Harness Routing Design
Cable Harness Installation and Test

Cleanrooms and Contamination Control Support:

ISO Class 7 Cleanrooms and Tents
Particle and Hydrocarbon Monitoring
Witness Plate Monitoring and Analysis
Cleanroom Garments and Supplies
Precision Cleaning

2.1 Mechanical Integration

The Center possesses both the facilities and personnel necessary for mechanically integrating spaceflight hardware, including instruments, ground support equipment, and complete spacecraft. The integration effort is provided from the inception of the program through launch and recovery. Integration is performed either in the cleanrooms or in the general laboratories, as appropriate. Contamination-sensitive flight hardware and systems are integrated in the cleanrooms, while sensitive hardware is completed in the general integration facilities.

2.1.1 Handling of Spacecraft

Typical spacecraft handling tasks include preparation of procedures, crane operations, proof testing and verification of lifting devices and handling carts. The Center has extensive facilities, hardware, and trained personnel for both routine and quick reaction handling tasks. Logistics for shipping, receiving, and packaging are also provided at GSFC and other offsite locations.

2.1.2 Fabrication Support

Frequently, quick reaction machining operations need to be performed so that spacecraft integration tasks will remain on schedule. Trained personnel, using precision equipment and facilities, are available to modify or fabricate critical components and hardware as required.

2.1.3 Assembly

Both Center and project-supplied hardware is used by the integration group in the assembly of flight systems. Precision assembly tools, measuring instruments, and trained personnel are used to ensure precise alignment and installation of flight hardware. Precision optical transit squares, interferometers, surface tables, inclinometers, electronic levels, heights gauges, laser trackers, and helio-precision measuring tools are some of the instruments used for this effort.

2.1.4 Functional Checks of Spacecraft Mechanisms

Center personnel perform weight, moment of inertia, center of gravity, and product of inertia measurements on flight hardware. Functional checks of hinged doors, solar panel deployment mechanisms, payload ejection system, and boom deployments are routinely conducted in accordance with the designer's and experimenter's specifications. Integration personnel also work closely with electronics personnel when installing electronic packages and routing electrical harnesses.

2.1.5 Field Support

When required, Center personnel are available for field support at contractor sites, launch sites, and other NASA installations. Typical operations performed during field support tasks are covered above.

2.1.6 Purge Systems

Spacecraft and shipping containers typically require a regulated flow of clean, dry gas to maintain a safety barrier to reduce contamination. Large and small systems can be designed to customer specifications, fabricated, and certified. Existing systems can be refurbished and brought up to current NASA specifications.

2.2 Thermal System Support Facility

Description: From the facilities the Thermal System Support Group provides personnel and production support for the development, design, procurements, and implementation of unique processes in layout, fabrication, and installation of multi-layer (MLI) for GSE and space flight equipment. Applications include flight spacecraft, instrumentation, optical components, mock-ups, and test fixtures. Products include thermal blanketing for space environments and adverse heat loads, attenuating Electromagnetic Interference (EMI), micrometeorite shields, and support for EVA crew tools and aids. These services are provided to all NASA centers and aerospace vendors and are not limited to the Goddard Space Flight Center facilities.

Mode of Operation: Technical support is provided to ensure thermal design, performance, fabrication, and installation requirements meet all NASA and Project instructions and guidelines, and adherence to ISO and Quality procedures posses the proper documentation. Technicians work with a variety if metalized and non-metalized thin films (ex. Mylar, GBK, Kapton, and AL FEP), fabrics (ex. Betacloth, E-glass, and Kevlar), foils (ex. Titanium, stainless steel, and aluminum), tapes and adhesives, as well as a variety of buttons and fasteners. Technicians work from drawing, models, and direct from the flight hardware to produce templates for the thermal blanketing. From approved templates GSE and Flight blanketing is produced. Work is performed primarily in one of the production labs, but is also done in integration or test areas, contamination-controlled areas, and offsite locations. Technicians are trained in clean room operations, secondary bonding, Electrostatic Discharge precautions and procedures, and working on flight hardware and instrumentation. Work performed includes patterning, fabrication, modification, refurbishment, repair, and installation of thermal blanketing and EVA Tools and Aids. Technicians provide test, integration, and launch support world-wide.

Physical Characteristics:

- Production Lab 1 (Room 019) is ~ 1800 square feet
- Production Lab 2 (Room N107) is ~ 396 square feet
- Production Lab 3 (Coming Soon)
- Maintain (2) Heavy Duty Industrial and (1) Light/Medium Sewing Machines
- Maintain (10) Fabrication Tables (6’ x 7’)



MLI Blanket Installation



MLI Blanket Installed

2.3 Cable/Harness and Electrical System Support Facility

Description: The Electrical Systems Support Group maintains the facilities and provides personnel and production support for the development, design, materials procurements, fabrication, testing, and installation of ground support and space flight electrical cabling, harnesses, circuit boards, and other electrical components and equipment. Engineering design, drawing, and procedural support is provided to project for all facets of electrical systems and wiring. Support includes design, fabrication, and installation of GSE and Flight cabling, harnesses, thermal systems support (i.e. heater, thermocouples), structural bonding, ground wire, GSE Test boxes, and proof testing for all products. These services are provided to all NASA Centers and aerospace vendors and are not limited to the Goddard Space Flight center facilities.

Mode of Operation: Each cable and/or harness is built to custom specifications and in accordance with GSFC and NASA procedures and requirements. The design and testing of flight and ground support harnesses is accomplished in accordance with GSFC Design and Manufacturing Standards (GSFC-733-HARN-01) for Electrical Harnesses and 565-PG-8700.2.1. All fabrication, modification, and repair activities are performed by technicians certified to the requirements of NASA-STD-8739.1, 8739.3, 8739.4, and GSFC WM01 for staking and conformal coating, flight hand soldering, crimp/cable, and harnessing, and ESD. Through these requirements and procedures, we can account for design factors, fabrication methods, testing, and certifications. After fabrication and validation, harnesses can be baked out, routed, installed, and integrated to flight hardware. All fabrication benches and area are set up to minimize electrostatic discharge potentials. If full ESD requirements are needed benches are set up and verified in clean room areas or ESD flow benches are used.

Physical Characteristics:

- Production Lab 1 (Room 104) is ~ 800 square feet
- Production Lab 2 (Room 033) is ~ 600 square feet
- Maintain Crimp Pull Testers, Pin retention tested, calibrated fabrication tooling, voltmeters, Hi-pot test equipment.
- Maintain ESD sensitive workbenches, (2) Flow Benches, and various areas/benches as required.
- Maintain 18-foot cable assembly bench.
- Maintain ~ Secured storage area for flight materials.



Harness

2.4 Cleanrooms

Description: Cleanrooms are designed and operated to maintain a classification of air cleanliness by introducing air into the room, tent, or bench with conditioned recirculatory or direct ambient air systems through a series of high efficiency (HEPA) air filters. The filtered air is maintained at specified velocities in a unidirectional flow pattern that causes contaminants generated within the facility to be carries away in the direction of the moving air stream. All cleanrooms are certified twice a year to the most up to date ISO 14644-1 standard.

Mode of Operation: Cleanrooms are monitored on a periodic basis to verify that the classification of the facility remains within specification. Cleaning is performed on a pre-determined or "as required" schedule based on classification monitoring results. Used cleanroom garments are continuously removed from the change rooms and replaced with fresh packaged garments. Project personnel are present inside the cleanrooms during test activity to ensure that proper cleanroom procedures are followed.

2.4.1 Spacecraft Checkout Area (SCA)

Size	17 m L x 11 m W x 10 m H (56' x 36' x 33')
South Wall Filter	5,664 m^3/min (200,000 ft 3/min) – horizontal flow
Air Velocity	30m/min (100'/min), minimum
Temperature	68 ± 2°F
Relative Humidity	45 ± 5%
Entrance (Hardware)	Rollup Door: 5.9 m W x 6.0 m H (19.4' x 19.7')
Cleanliness	ISO Class 7
Other Services	Electrical, Compressed Dry Nitrogen, under-floor cable tray system, telephone and intercom, outlets for central vacuum
Other Parameters	The walls and exposed steel are painted with an epoxy paint to keep particle generation to a minimum. The concrete floor has a polyurethane coating.

2.4.2 RFI Shielded Room

Size	18 m L x 21 m W x 5.8 m H (59' x 69' x 19')
South Wall Filter	Horizontal Flow
Air Velocity	60 fpm
Temperature	68 ± 2°F
Relative Humidity	45 ± 5%
Entrance (Hardware)	High Speed Rollup Door: 6.1 m W x 5.7 m H (20' x 18.6')
Cleanliness	ISO Class 7 (M5.5)
Other Services	4 nitrogen, 4 compressed air, fire alarm monitoring, emergency lighting, 30" x 40" pass-through area, power strip, copper grounds, fully redundant air-handling system, modular clean-room, 14" north and south wall touch screen displays indicating clean room environment, 5-ton crane w/hook height of 5.6 m (18'3"), area outside of cleanroom maintained at 20±4.5°C (72±8°F)
Other Parameters	There is a gowning room that is equipped with HEPA filters (2.3 m W x 7 m L x 5.8 m H) in the ceiling. 208V, 100amp bus rails are on the outside of the cleanroom for EGSE.

2.4.3 Space Environment Simulator (SES)

Size	8.2 m diameter x 12.2 m H (27' x 40')
Air Flow	283 m^3/min (10,000 ft^3/min)
Temperature (Nominal)	19.8 m/min (65'/min), minimum
Temperature (Nominal)	21°-C (70°F)
Relative Humidity	Below 60%
Anteroom	Basement Level/Bldg. 10, first floor
Personnel Entry	Basement Level through NE corner
Cleanliness	ISO Class 7 (M5.5)
Other Services	Electrical, telephone and intercom, compressed dry nitrogen, outlets for central vacuum
Other Parameters	The walls and exposed steel are painted with an epoxy paint to keep particle generation to a minimum. The floor has a torginol seamless quartz coating.

2.4.4 10/120 (Whitehouse) Cleanroom

Size	8.2 m diameter x 12.2 m H (27' x 40')
Air Velocity	283 m^3/min (10,000 ft^3/min)
Temperature	19.8 m/min (65'/min), minimum
Relative Humidity	Below 60%
Entrance (Hardware)	Basement Level through NE corner
Cleanliness	ISO Class 7 (M5.5)
Other Services	Electrical, telephone and intercom, compressed dry nitrogen, outlets for central vacuum
Other Parameters	The walls and exposed steel are painted with an epoxy paint to keep particle generation to a minimum. The floor has a torginol seamless quartz coating.



White House Clean Room (viewed from B10 High Bay)

2.4.5 29/160 Cleanroom

Size	18 m L x 21 m W x 5.8 m H (59' x 69' x 19')
Air Flow	2100 m^3/min (74000 ft^3/min) – horizontal flow
Air Velocity	30m/min (100'/min)
Temperature	20±2°C (68±2°F)
Relative Humidity	45±5%
Entrance (Hardware)	High Speed Rollup Door: 6.1 m W x 5.7 m H (20' x 18.6')
Cleanliness	ISO Class 7
Other Services	4 nitrogen, 4 compressed air, fire alarm monitoring, emergency lighting, 30" x 40" pass-through area, power strip, copper grounds, fully redundant air-handling system, modular clean-room, 14" north and south wall touch screen displays indicating clean room environment, 5-ton crane w/ hook height of 5.6m (18'3"), area outside of cleanroom maintained at 20±4.5°C (72±8°F).
Other Parameters	There is a gowning room that is equipped with HEPA filters (2.3 m W x 7 m L x 5.8 m H) in the ceiling. 208v, 100amp bus rails are on the outside of the clean room for EGSE.



Outside 29/160 Cleanroom



Inside 29/160 Cleanroom

2.4.6 15/151 Cleanroom

Size	4.8 m L x 5.4 m W x 4.2 m H (17'7" x 16' x 14')
Air Flow	141 m^3/min (5000 ft^3/min) total air – vertical flow
Air Velocity	25m/min (85'/min)
Temperature	22±2°C (72±2°F)
Relative Humidity	45±5%
Entrance (Hardware)	Two entrances to cleanroom: One (1) Double Door 1.8 m W x 2.1 m H (6ft W x 7ft H) One single door (opens into gowning) 0.9 m W x 2.1 m H (3' x 7')
Cleanliness	ISO Class 6
Other Services	Sprinkler System, emergency lights, fire alarm system (horn & strobe), compressed air outlets, duplex 120V 20-amp receptacles



Figure 3 15/151 Cleanroom from the Outside

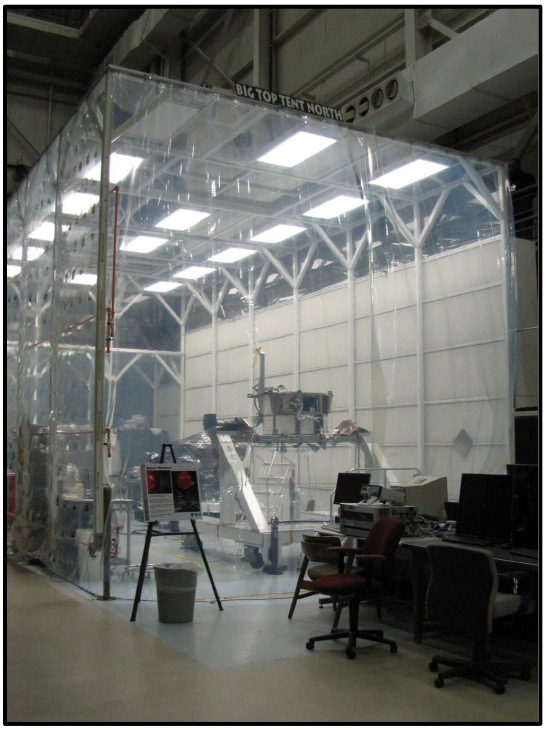
2.4.7 Cleanroom Tents

Building 7 High Bay (150 Tent)	
Size	6.1 m W x 9.1 m L x 4.7 m H (20' x 30' x 15.4')
Air Flow	1,303m^3/min (46,000 ft^3/min) – horizontal flow
Air Velocity	15m/min (50'/min)
Cleanliness	ISO Class 7
Air Velocity	30m/min (100'/min)
Entrance	6.1 m W x 4.7 m H (20' x 15.4') roll up curtain
Tent Material	Anti-Static Polyethylene
Temperature/Humidity	Not Controlled (Subject to building's ambient conditions

Building 10 High Bay (Big Top Tent)	
Size	11.3 m W x 5.5 m L x 5.3 m H (37' x 18' x 17.5')
Air Flow	1,869m^3/min (66,000 ft^3/min) – horizontal flow
Air Velocity	27m/min (90'/min)
Cleanliness	ISO Class 7
Air Velocity	30m/min (100'/min)
Entrance	5.5 m W x 5.3 m H (18' x 17.5') roll up curtain
Tent Material	305micron (12mil)
Temperature/Humidity	Not Controlled (Subject to building's ambient conditions



Figure 4 Building 7 High Bay Clean Tent (Top) Building 10 High Bay Clean Tent (Bottom)



2.4.8 Special Payloads Operations and Testing (SPOT) Clean Tents

Description: There are two (2) movable SPOT tents that may be used separately, or together, to provide integration and test areas. The down-flow tents have wheels attached to their legs for easy positioning. Two of the four tents have crane access hatches in the ceiling for payload handling.

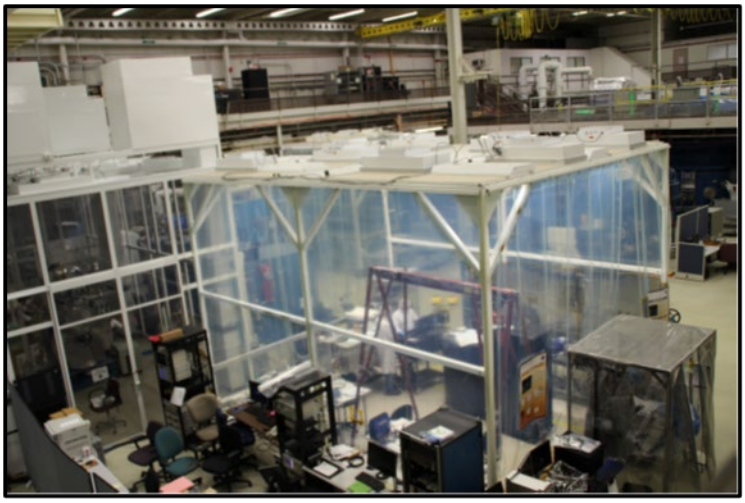
Mode of Operation: Normally, the tents are monitored each week when in use, depending on the protocol established by the user. The tents are cleaned on an "as required" basis, and cleanroom garments are supplied as required by the cleanliness specification and project activity level.

Spot Clean Tents	
Size	6.1 m L x 4.9 m W x 4.9 m H (20' x 16' x 16')
Air Flow	27 m/min (90'/min) – vertical flow
Air Velocity	Variable – nominal 425 m^3/min (15000 ft^3/min)
Cleanliness	ISO Class 7
Temperature/Humidity	Not Controlled (Subject to building's ambient conditions
Other Parameters	Wheels on all four legs, static dissipative tent material, copper grounding



2.4.9 Portable Down Flow Tents

Portable Down Flow Tents	
Size	2.44 m L x 1.22 m W x 3.66 m H (4’ x 8’ x 12’)
Support	Free Standing (usually have wheels on all four legs)
Cleanliness	ISO Class 7
Temperature/Humidity	Not Controlled (Subject to building’s ambient conditions
Other Notes	Tents can be interlocked to form a 2.4 m W x 2.44 m L (8’ x 8’) module. They have side curtains of anti-static nylon, and ceiling installed fluorescent lights. Blower units are either integral in the ceiling or stand-alone units on the floor.



2.4.10 Unidirectional Flow Clean Bench

Several unidirectional flow clean benches are available. The working areas range from 1.22 m (4') wide, 0.61 m (2') deep, and 0.61 m (2') high, to 1.52 m (5') wide, 0.91 m (3') deep, and 0.91 m (3') high. The entire back wall of the clean bench is a high efficiency filter through which air passes at 30m/min (100'/min). The unit has no air conditioning but may contain lighting. These benches can be maintained at an air cleanliness classification of ISO Class 5.



Unidirectional Flow Clean Bench

2.4.11 Portable Particle Counters

Contamination control owns six (6) particle counters that read 0.3, 0.5, 1.0, 3.0, 5.0, 10 um range. All particle counters are calibrated yearly.

Particle counters are reserved for 549 contamination control use and not continuous room monitoring.

2.4.12 Pressure, Temperature, and Humidity Monitoring

Cleanroom pressure, temperature, and humidity monitoring is done by a Tridium open-source system in the SCA, RFI, 160, White House, and SSDIF cleanrooms. Contamination control engineering, facility engineering, and maintenance have remote access to the system, and can respond 24/7. Data for these cleanrooms are retained for 5 years minimum but can be changed per project request.

Clean tents and SPOT tents are NOT monitored, unless requested.

2.4.13 Contamination Monitoring and Analysis Lab

Continuous contamination monitoring for non-volatile residue (NVR) is performed in all cleanrooms. Analysis is performed per IEST-STD-CC1246E, and data is trended for all cleanrooms.

Rapid analysis lab also has rapid testing capabilities, including:

- NVR weights
- FTIR
- GCMS liquid samples
- GCMS gas samples
- Ambient off gas testing

2.4.14 Spacecraft Systems Development and Integration Facility (SSDIF), Bldg. 29

Description: The SSDIF is a 7,989 m^2 (86,000 ft^2) facility designed to provide support for the integration and testing of spacecraft hardware. It is unique in the fact that it contains a 36,816 m^3 (1.3 million ft^3) horizontal, unidirectional flow cleanroom. Additional features include:

- Automated data processing area
- Shipping/Receiving Area
- Flight Hardware Storage Area
- Precision Cleaning Facilities

SSDIF High Bay Cleanroom

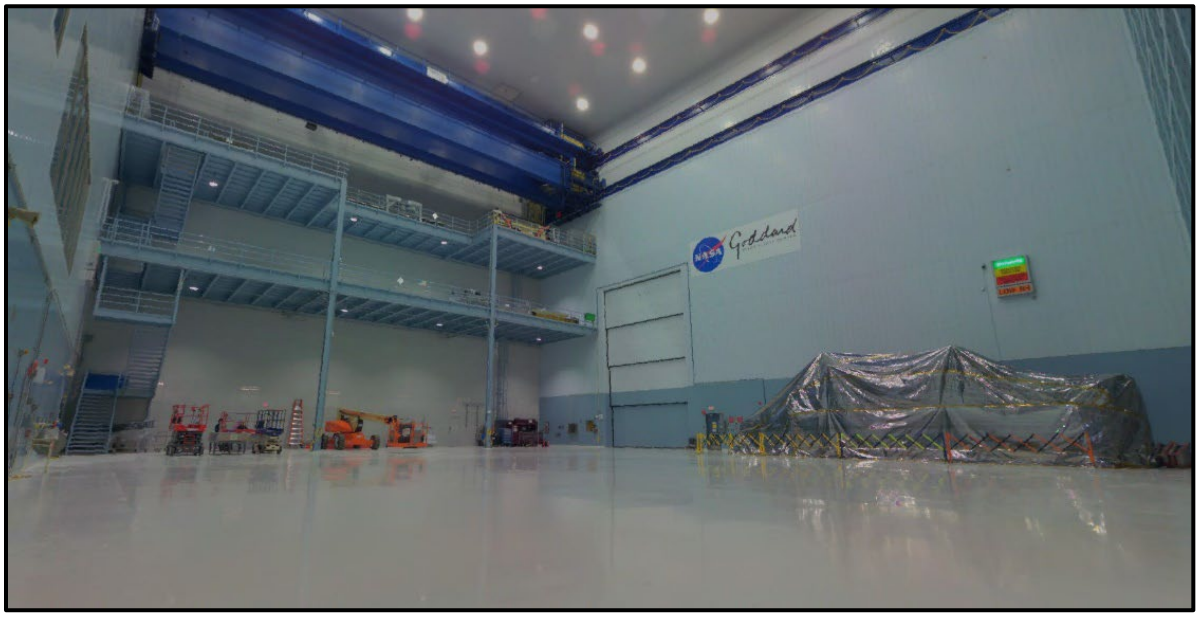
Description: The High Bay Cleanroom is a 1,161 m^2 (12,500 ft^2), ISO Class 7

Horizontal unidirectional flow cleanroom. It has been designed to support the integration and testing of flight hardware and has the capacity to accommodate two full-sized shuttle payloads simultaneously. A cable tray provides data cable access to the Automated Data Processing Room. Access to the cleanroom is via a 7.6 m x 12.2 m (25' x 40') overhead roll up door. Two 31,752 Kg (35-ton) cranes, with hook heights of 21.0 m (69') and 24.4 m (80'), provide lift and transport capabilities. Materials of construction have been selected, and procedures designed, to minimize molecular and particulate contamination levels within this facility.

Mode of Operation: A computer-based automatic control system monitors and controls environmental parameters on a 24-hour basis. Only approved personnel and materials are allowed to enter the cleanroom, and procedures are strictly enforced to maintain cleanliness of the facility. On-site contamination control personnel provide cleanroom support services such as; certification, monitoring, facility cleaning, maintenance of the change room, and precision cleaning.

Spacecraft Systems Development and Integration Facility	
Size	38 m L x 30 m W x 27 m H (125' x 100' x 89')
Air Flow	25000 m^3/min (900000 ft^3/min)
Air Velocity	30m/min (100'/min), minimum
Cleanliness	ISO Class 7 automatic real time monitoring
Temperature	20±2°C (68±2°F)
Relative Humidity	45±5%
Entrance (Hardware)	Rollup Door: 7.6 m W x 12.2 m H (25' x 40')
Bonded Storage	Two identical areas, one atop the other
Cranes	2 x 31,752 Kg (35-Ton) Hook Heights of 21.0 m (69') and 24.4 m (80')
Other Services	Compressed air and nitrogen, telephones, video monitoring

SSDIF High Bay Cleanroom (facing south-west)





SSDIF High Bay Cleanroom (facing north-east)

SSDIF Precision Cleaning Room

Description: The precision Cleaning Room is a 55 m^2 (592 ft^2), ISO 6 horizontal, unidirectional flow cleanroom. It was designed to supply precision cleaning services for spacecraft hardware and ground support equipment. This area contains the necessary services, equipment, and supplies, including a Quadrex Shear Stress Precision Cleaning System.

Mode of Operation: The facility is staffed with trained precision cleaning personnel.

Providing a variety of cleaning services. Complete, detailed procedures govern all applications, and QA personnel provide inspection capability for all cleaned parts. Access to the facility is restricted, and operations are supported by a 46 m^2 (500 ft^2) Pre-Cleaning Room.

SSDIF Precision Cleaning Room	
Size	8.5 m L x 6.4 m W x 3.0 m H (28' x 21' x 10')
Air Flow	793 m^3/min (28,000 ft^3/min) – horizontal flow
Air Velocity	30m/min (100'/min), minimum
Cleanliness	ISO Class 6
Temperature	20±2°C (68±2°F)
Relative Humidity	45±5%
Entrance (Hardware)	Two 1.83 m (6') double doors, one with airlock; Passthrough
Other Services	Services are located as required – See facility layout drawings for details, shear stress precision cleaning system, compressed nitrogen, video monitoring, communication system.

3.0 FACILITY SUPPORT SERVICES

A variety of services are needed to support the integration and test activities within the I&T complex. Code 549 maintains and upgrades these systems to ensure all activities within the complex occur seamlessly and safely. Contact your Code 549 representative for more information if utilities or capabilities are needed in a work area.

3.1 Electrical Power

3.1.1 Normal House Power (Commercial)

Normal house power in buildings 7, 10, 15, and 29 complex consists of the following circuits:

Voltage (AC)	Hz	Phase	Current (AMP)
120/208	60	3	Up to 100
277/480	60	3	Up to 100

The primary electrical source to each bldg. consists of 2-13.8 kVA feeders:

- Each building has a total of 2-loadcenter.
- Each Load Center is double ended with an open tie breaker.
- One Load Center is for 120/208 voltage system.
- One Load Center is for 277/480 voltage system.

Designated circuits in Bldgs. 7 and 10 are backed up by an emergency generator power source. It should be noted that all transformers are Y connected with the center tap grounded.

Instrument grounding plates are available throughout the complex.

3.1.2 Emergency Power Systems

Building 7 Emergency Power

Description: The emergency power system for the test facilities in Buildings 7 consists of a 500-kW diesel generator. The generator and the associated automatic transfer switch are permanently installed outside and in the basement of B7 respectively. Electric panels on generator are labeled AX-# (i.e. AX-1).

Mode of Operation: The generator will start and transfer automatically to the equipment tied into the B7 emergency panels when commercial power has been lost longer than 30 seconds. Power transfer back to the facility utilities is executed manually. The generator feeds B7 TVAC labs and support equipment as well as 4 ultra-low temperature freezers (3 located behind the 150 clean tent and 1 located in B7/R190). Due to the limited capacity of this unit, the standard procedure after a power failure is to initiate an orderly restart of selected facilities up to the capacity of the emergency system. For a power outage, test conditions are maintained for at least one hour by the emergency generator (or longer based on fuel consumption).



B7 Emergency Generator

Building 10 Emergency Power

Description: The emergency power system in Building 10 consists of a 350-kW diesel generator. The generator and associated automatic transfer switch are permanently installed outside of B10. Electrical panels on the generator are labeled with an orange EMERGENCY POWER label on the front.

Mode of Operation: The generator will start and transfer automatically to the equipment tied into the B10 emergency panels only when the SES Chamber is running, and commercial power has been lost longer than 15 seconds. Power transfer back to the facility utilities is executed manually. The generator feeds SES chamber and surrounding receptacles designated for SES support equipment. Due to the limited capacity of this unit, normal procedure after a power failure is to initiate an orderly restart of selected facilities up to the capacity of the emergency system. For a power outage, test conditions are maintained for at least one hour by the emergency generator (or longer based on fuel consumption).



B10 Emergency Generator

3.2 High Pressure GN2 Generating and Storage Systems (Facilities 258 and 263)

Description: There are separate high pressure GN2 generating and storage systems for Buildings 7 and 10. The Building 7 system is comprised of two liquid pressurization pumps, an ambient air heat exchanger, and a manifolded rack of forged steel gas storage bottles. The building 10 system has a dual pump arrangement with a single ambient air heat exchanger. The buildings 7 and 10 GN2 storage systems are connected, isolated from each other, and primarily filled by the building 7 GN2 system, with the building 10 GN2 system serving as secondary.

Mode of Operation: The high-pressure pump increases the liquid pressure to 13.8 MPa (2000 psig). The liquid is evaporated in the heat exchanger and transferred to the storage bottles which are maintained at 14.1 MPa (2,045 psig) maximum. The gas is withdrawn for use in each building after a two-stage pressure reduction to 2.4 MPa (350 psig) and 0.69 MPa (100 psig), respectively.

Parameters:

GN_2 Generation:	227 standard m^3/hr (8,000 ft^3/hr) each pump
Storage Capacities:	Bldg. 7 -719 standard m^3 (25,400 ft^3)
	Bldg. 10 – 2,322 standard m^3 (82,000 ft^3)

Physical Characteristics:

	Building 7	Building 10
Pressurizing engine pump:	1	2
LN_2 storage dewar – 1,893 lit (500 gal):	1	1
Vaporizing heat exchange:	1	1
Storage Bottles:	3	12



Building 10 Vaporizer





Building 10 GN_2 Storage Bottles

3.3 Crane Capabilities

It is recommended that crane users conduct a site inspection to verify limit switch repeatability if their job requires hook heights within a few inches of the limits shown below. For example, gear-type limit switches may repeat within only a couple of inches on some cranes.

*TYPE (Except as otherwise noted, the cranes are bridge cranes.)

A – Variable Hoist Control
B – Trolley Crane (No Bridge)
C – Hoist Only (No Trolley or Bridge)
D – Dual Trolley
E – Wooden Traversing

LQMS Device No.	Old Device No.	Location	*Type	Capacity (LBS)	Hook Height (ft & in)
GB-BRDG-9	7-4	Rm 040, Vib Lab	A	15000	45' to Basement 25' to B10 Floor
GB-BRDG-10	7-6	Rm 036, Vib Lab	A	15000	45' to Basement 25' to B10 Floor
GB-MONO-9	7-9	Rm 026, Vib Lab	B	4000	14'3"
GB-MONO-10	7-10	Rm 026, Vib Lab	B	4000	14'3"
GB-BRDG-11	7-13	Truck Lock	A	20000	34'
GB-MONO-11	7-14	Rm 190A, Integration	B	4000	13'4"
GB-MONO-12	7-15	Rm 190A, Integration	B	4000	13'4"
GB-BRDG-12	7-16	High Bay Lab	A	10000	27' to Floor 13' to Mezzanine
GB-BRDG-13	7-17	High Bay Lab	A	10000	27' to Floor 13' to Mezzanine
GB-BRDG-14	7-18	SCA Clean Room	A	10000	27'
GB-BRDG-15	7-19	CIA Clean Room	A	15000	42'11" to Basement 13' to Mezzanine
GB-BRDG-16	7-30	Acoustic Chamber	A	15000	34'8"
GB-BRDG-18	10-1	High Bay Lab	A	30000	65'6"
GB-BRDG-19	10-2	White House Clean Rm	A	20000	50'3"
GB-BRDG-37	10-5	Rm 130 Lab	A	4000	12'
GB-BRDG-21	15-2	High Bay Lab	A	15000	38'8"
GB-MONO-16	15-3	HCC Rotunda (east)	B	6000	25'3"
GB-MONO-17	15-4	HCC Rotunda (west)	B	15000	27'5"
GB-BRDG-22 / GB-BRDG-23	15-5	Modal Test Facility	A	2000	14'6"
GB-BRDG-24	15-6	Modal Test Facility	A	1000	18'
GB-BRDG-25	15-7	Modal Test Facility	A	1000	21'10"

GB-BRDG-28	29-1	SSDIF Clean Room – Lower Crane	A	70000	67'3" to Floor 30'9" to Lower Mezz 13'8" Upper Mezz
GB-BRDG-29	29-2	SSDIF Clean Room – Upper Crane	A	70000	78'6" to Floor 45'1" to Lower Mezz 25'1" to Upper Mezz
GB-BRDG-30	29-3	Rm 140, North High Bay	A	70000	64'7"
GB-BRDG-31	29-4	Rm 140, South High Bay	A	70000	65'
GB-BRDG-32	29-5	Rm 150	A	10000	39'5"
GB-BRDG-33	N/A	Rm 160	A	10000	18'3"
TBD	303 30-8	Central Coil Building	E	2400	25'
TBD	305 30-1	Inner Truck Lock	B	6000	13'10"
TBD	305 30-2	South Side of Building	C	5000	22'
TBD	305 30-3	Coil Centerline	C	5000	19'
GB-MONO-25	305 30-4	Outer Truck Lock	B	5000	19'

3.4 Mobile Aerial Work Platforms and Powered Industrial Truck Devices

The following MEWP and PIT devices are owned and managed by Code 549. The vehicle fleet will change over time and should be verified through LQMS (https://lqms.gsfc.nasa.gov/) for accuracy.

Device #	Manufacturer	Model	Capacity
GB-MAP923-8	JLG	FT70	330
GB-MAP923-9	JLG	Blank	330
GB-MAP925-8	JLG	E600JP	500
GB-MAP926-1	Genie	GS-1930	500
GB-MAP926-2	Genie	GS-1930	500
GB-MAP926-3	Genie	GS-2632	500
GB-MAP926-11	Skyjack	SJIII 3220	800
GB-MAP926-12	Marklift	CH20NP	800
GB-MAP926-13	Skyjack	3220	800
GB-MAP926-14	Skyjack	3220	800
GB-MAP926-15	Skyjack	SJIII 4626	1000
GB-MAP926-16	Skyjack	SJIII 4626	1000
GB-MAP926-18	Genie	QS20	350
GB-PIT561-43	Clark	C70	15400
GB-PIT561-44	Hyster	N35ZRS-145	3500
GB-PIT561-45	Clark	EC500-100	9500
GB-PIT561-55	Hyster	W60Z	6000
GB-PIT561-57	Toyota	7FBCU45	10000
GB-PIT561-60	Crown	BS645	1500
GB-PIT569-1	Raymond		200
GB-PIT569-2	Raymond		200
GB-PIT569-3	Pettibone	A550-89	200

3.5 Doorways and Other Clearances

These dimensions are listed to assist flight projects in their logistic planning efforts. Building modifications or staged hardware may cause these dimensions to change or otherwise obstruct movement of hardware. Prior to moving large items, passageways should be walked down and/or coordinated with the FOM. All items left in the complex must be labeled with the name, phone number, and project of the person responsible for them.

Door Location	Description	Dimensions (W x H)
B7 to B10	Roll Up Door	19'2" x 18'11"
B7 Rm 008 (Small RFI) to Basement	Hinged Doors	7' x 7'3"
B7 Rm 026 (Small Vibe Cell) to Basement	Hinged Doors	8'2" x 16'8"
B7 Rm 036 (North Vibe Cell) to B10 Rm 100 (High Bay)	Hinged Doors	16'2" x 29'5"
B7 Rm 040 (South Vibe Cell) to B10 Rm 100 (High Bay)	Hinged Doors	16'2" x 29'5"
B7 Rm 108 (SCA North) to Rm 150 (High Bay)	Roll Up Door	19'8" x 20'
B7 Rm 108 (SCA South) to Rm 150 (High Bay)	Roll Up Door	19'8" x 20'
B7 Rm 108 (SCA) to Rm 108A (Large RFI)	Hinged Doors	18'6" x 17'11"
B7 Rm 108 (SCA) to Rm 108B (CIA)	Roll Up Door	11'3" x 16'6"
B7 Rm 150 (High Bay) to Rm 190 (Integration Area)	Roll Up Door	10'11" x 13'10"
B7 Truck Lock to B10	Roll Up Door	15'11" x 13'11"
B7 Truck Lock to Outside	Roll Up Door	15'3" x 15'2"
B7 Truck Lock to Rm 190 (Integration Area)	Roll Up Door	11'9" x 13'11"
B10 to B15	Roll Up Door	20' x 19'11"
B10 to B29	Leaf Door	25' x 31'
B10 Rm 110 (Acoustic Fac) to B10 Rm 100 (High Bay)	Hinged Doors	14'11" x 33'11"
B10 Rm 120 (White House) to B10 Rm 100 (High Bay)	Roll Up Door	25' x 40'
B15 to HCC Rotunda	Hinged Doors	24' x 23'6"
B15 to Outside	Roll Up Door	23'11" x 20'7"
B29 Rm 130 (SSDIF) to Rm 140 (High Bay)	Leaf Door	25'3" x 29'6"
B29 Rm 140 (High Bay) to Outside	Roll Up Door	25' x 24'11"
B29 Rm 140 (High Bay) to Rm 150	Roll Up Door	24'11" x 24'11"
B29 Rm 140 (High Bay) to Rm 150	Roll Up Door	19'11" x 19'5"
B29 Rm 160 to Outside	Roll Up Door	16'2" x 17'7"
B29 Rm 160 to Rm 160A (Cleanroom)	Roll Up Door	19'10" x 18'2"

Other Clearances	Description	Dimensions (W x H)
B7 Bridge over B7 – B10 Corridor (Highest Clearance)	Walkway	16'7" x 17'10"
B7 Duct over B7 – B10 Corridor	HVAC Duct	18' x 19'2"
B7 Freight Elevator	Elevator	10' x 9'7" x 7'6"
B7 Lift (Vibe Area to Basement Floor)	Elevator	5'10" x 8'5" x 8'8"
B7 Floor Hatch near Freight Elevator	Floor Hatch	12'10" x 16'10"
B10 Floor Hatch near SES Chamber	Floor Hatch	10' x 20'
B10 Floor Hatch near Truck Lock	Floor Hatch	9' x 10'

3.6 Air Bearing Supply Stations

The house air system delivers compressed air at 621 Kpa (90 psig) pressure with a maximum volume of 2.83m^3(100ft^3)/min. Connections are via a Hansen 2.54cm (1") quick disconnect and are available at the following locations:

Building	Room	Location
B7	High Bay	South Wall (West)
B7	High Bay	South Wall (Center)
B7	High Bay	South Wall by Rm 188 (east)
B15	High Bay	West Wall
B10	High Bay	B15 High Bay Door
B10	High Bay	B7 High Bay Door
B10	High Bay	Truck Lock Door
B29	SSDIF	Center Mezzanine Column
B29	SSDIF	NE Corner
B29	140 (High Bay)	South Wall
B29	140 (High Bay)	North Wall
B29	160 (High Bay)	West of 29/160 Cleanroom Roll-Up
B29	160 (Cleanroom)	NE Column
B29	160 (Cleanroom)	NW Column
B29	160 (Cleanroom)	SE Column
B29	160 (Cleanroom)	SW Column

3.7 Air Bearings

Description: Air bearings provide smooth mobility for heavy loads. By securing the air bearings to an object and applying air pressure, the object rides on a cushion of air and is easily moved and maneuvered. Air bearings (aka air casters), air-pressure manifolds, and air lines are managed by the 549-tool crib (Bldg. 7/Rm 176A). Inventory is subject to change and should be verified with the 549-tool crib manager.

Quantity	Size	Capacity
6	¾" ID x 10' – 25' length	150 psi
4	1 ¼" ID x 50' length	150 psi
4	12" diameter pad	1T/25 psi
2	15" diameter pad	2.125t/30psi
2	15" diameter pad	1.75t/25psi
8	21" diameter pad	3.5T/25psi
4	27" diameter pad	6T/25psi

3.8 GN_2 Purge Outlets

Description: Gaseous nitrogen is available for purge at various locations in the cleanrooms. A GN_2 supply can be installed for special applications at any location in the building 7/10/15/29 complex when defined by the experimenter in advance.

Location	Supply Line	Maximum Delivery Pressure	Connection
SCA Cleanroom (4 Locations)	0.95cm (3/8") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
CIA Cleanroom (2 Locations)	0.95cm (3/8") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
SSDIF Cleanroom (6 Locations)	1.3cm (1/2") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
SES Chamber (3 Locations)	1.3cm (1/2") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
Acoustic Chamber (1 Location, Column 16K)	0.95cm (3/8") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
Vibration Cell, Rm 36 (1 Location)	0.95cm (3/8") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
Vibration Cell, Rm 40 (1 Location)	0.95cm (3/8") Nominal	621 kPa (90psig)	0.64cm (1/4") Swagelok Fitting
Thermal Vacuum Chambers, Bldg. 7 (At each facility)	Varies	621 kPa (90psig)	Varies (All can be adapted to ¼" Swagelok fitting)
160 Cleanroom (4 Locations)	0.95cm (3/8") Nominal	621 kPa (90psig)	Can be adapted to ¼" Swagelok fitting
160 Pre-Clean (Rm 160) (1 Location)	0.95cm (3/8") Nominal	621 kPa (90psig)	Can be adapted to ¼" Swagelok fitting
Bldg. 29 HB NW Corner Outside of Rm 160 (1 Location)	0.95cm (3/8") Nominal	621 kPa (90psig)	Can be adapted to ¼" Swagelok fitting

3.9 LN_2 Fill Stations

Description: LN2 stations for dewar filling are provided in the locations shown:

Location	Supply Line	Maximum Delivery Pressure	Connection
Bldg. 7 Basement Near Column G-6	1.3cm (1/2") nominal	172 kPa (25psig)	1.3cm (1/2") American National Fitting
West Wall – Facility 255 LN_2 Storage Shed	1.3cm (1/2") nominal	172 kPa (25psig)	1.3cm (1/2") American National Fitting

The requirements to use the fill stations are cryogenic gloves and a face shield.

3.10 LN_2 Storage Vessels

Large quantities of liquid nitrogen are maintained to provide cryogenic cooling of cryopumps, cold fingers, diffusion pump cold traps and shrouds of the thermal vacuum chambers in Buildings 7 and 10, and as a supply for the high-pressure gas generators. Also, small portable vessels can be filled at the building 7 facility.

3.10.1 Building 7, 106K Liter (28K Gal) Dewar (Facility 255)

Description: This double-walled, vacuum-jacketed storage vessel is comprised of two concentric, horizontal cylinders. The outer shell, made of carbon steel, is 18.3 m (60') long by 3.7 m (12') in diameter. The inner tank, fabricated from stainless steel, has a capacity of 106 K liters (28,000 gallons) of LN2 with a 5,299-liter (1,400 gallon) ullage volume. An ambient temperature vaporization coil maintains a tank pressure of 172 kPa (25 psig). Valves are provided to control the filling and withdrawal of the cryogenic fluid.

Mode of Operation: Insulated plumbing conducts the cryogenic fluid to a distribution manifold in Building 7, where it is transferred as required to each chamber and withdrawal station through insulated or vacuum-jacketed lines.

3.10.2 Building 10, 242K Liter (64K Gal) Dewar (Facility 257)

Description: This double-walled, vacuum-jacketed LN2 dewar is comprised of two concentric spheres supported by tubular columns. The 7.9 m (26') diameter inner vessel is constructed of welded aluminum plates and the 8.5 m (28') diameter outer casing is constructed of welded steel plate. The inner tank has a capacity of 242K Liters (64,000 gallons) with a 22.7 K Liter (6,000 gallon) ullage Volume. An ambient temperature vaporization coil provides a tank pressure of 172 kPa (25 psig). Valves are provided to control the supply and withdrawal of LN2.

Mode of Operation: Insulated plumbing conducts the cryogenic fluid to a distribution panel in the basement of Building 10, where it is directed as required to the cryopumps, the thermal system, and the shroud LN2 recirculating system.

3.11 Portable Air Conditioning (PAC) Units

Introduction: There are 3 Clestra Cleanroom, 2 Movincol Classic Plus 26, and 1 Movincool Classic Plus 14 portable air conditioning (PAC) units available in the complex to provide cooling for spacecraft hardware. The PAC units process air by altering its temperature and humidity properties to produce an environment to meet the conditions favorable to the projects during hardware integration and testing. The PAC units are maintained by Code 549.

Parameters:

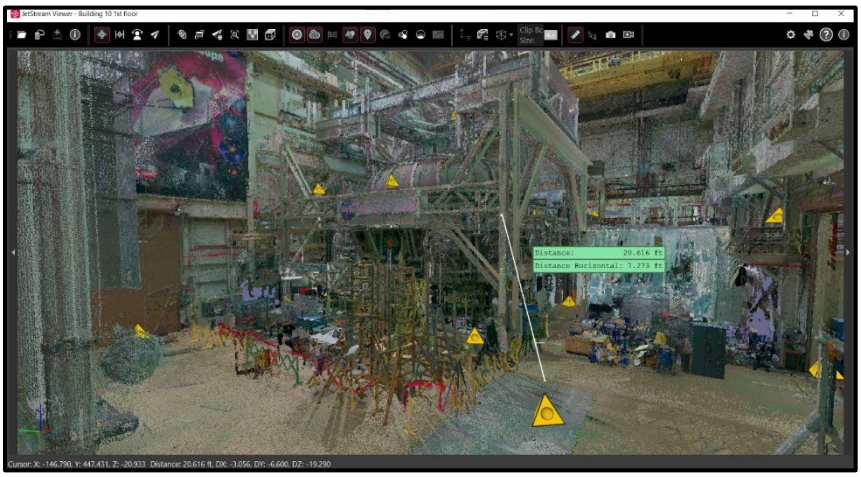
	Cleastra Cleanroom	Movincool Classic Plus 26	Movincool Classic Plus 14
Airflow	800 CFM	1680/1460 CFM	440/380 CFM
HEPA Filter	99.99% @ 0.3µ	None	None
Cooling Capacity	4T (48,000 BTU/Hr)	2T (24,000 BTU/Hr)	1.1T (13,200 BTU/Hr)
Temperature Control	±1˚C	±1˚C	±1˚C
Dehumidification Control	None	None	None
Electrical	240V 3P	220V 1P NEMA 6-20	120V 1P NEMA 5-15
Refrigerant	R-410a	R-410a	R-410a



PAC Units #1, #2, and #3

3.12 Jetstream Viewer

Introduction: Jetstream Viewer is a free application published by Leica, which allows connection to a Jetstream server for viewing of 3D point-cloud files housed on that server. It allows virtual walk-throughs, visualizations, point-to-point measurements, temperature measurements, and high-res panoramic 360 photos of scanned facilities/equipment. Many of the facilities in this handbook have been scanned in this fashion and are available for viewing. All these scans are stored within a Code 549 server. Contact a Code 549 representative for assistance in accessing this collection of scans or to request additional scans for viewing.



Sample Building 10 Jetstream Viewer Point-Cloud scan with point-to-point measurement



Leica Laser Scanner

APPENDIX – A: ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation Symbol	Translation
“	Inch
‘	Foot
<	Less than
>	Greater than
%	Percentage
µ	Micro
Å	Angstrom
A	Ampere
AC	Alternating Current
A/C	Air Conditioning
Amp	Ampere
AN	American National
ANSI	American National Standards Institute
B or Bldg.	Building
˚C	Degrees Celsius
CCTV	Closed Circuit Television
C/F	Cold Finger
CFm or cfm	Cubic Feet Per Minute
CG	Center of Gravity
CIA	Calibration Integration Alignment
Cm	Centimeter
Col	Column
CRT	Cathode Raytube
D	Diameter
dB	Decibel
DC	Direct Current
DEC	Digital Equipment Corporation
Dia	Diameter
Dim	Dimension
Ea	Each
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
˚F	Degrees Fahrenheit
FM	Frequency Modulation
Fpm	Feet Per Minute
FRF	Frequency Response Function
Ft	Foor or Feet
G	Gram
G	Unit of Acceleration
Gal	Gallon
GN_2	Gaseous Nitrogen
GSFC	Goddard Space Flight Center
H	Height
HCC	High-Capacity Centrifuge
Hdwe	Hardware

Abbreviation Symbol	Translation
HEPA	High Efficiency Particulate Air
HgXe	Mercury Xenon
Hp	Horsepower
HP	Hewlett-Packard
Hr or hr	Hour
HST	Hubble Space Telescope
HVAC	Heating, Ventilation, and Air Conditioning
Hz	Hertz (Cycles Per Second)
IIF	Instrument Interface Flange
In	Inch
ITD	Instrument Test Dewar
IVS	Instrument Vacuum Space
JSC	Johnson Space Center
˚K	Degrees Kelvin
kB	Kilobyte
Kg	Kilogram
kPa	Kilopascal
KSC	Kennedy Space Center
kVA	Kilovolt Ampere
KW or Kw	Kilowatt
L or l	Liter
Lb or lb	Pound
LHe	Liquid Helium
Lit/sec	Liter Per Second
LN_2	Liquid Nitrogen
LVDT	Linear Variable Differential Transformer
M or m	Meter
MAP	Microwave Anisotropy Probe
Max	Maximum
MB	Megabyte
MB C220	MB C220 Vibrator Exciter
MicroVAX	DEC Computer
MIL STD	Military Standard
Min	Minute
Mitoc	Communications System
MLI	Multi-Layer Insulation
Mm	Millimeter
MOI	Moment of Inertia
MPMF	Mass Property Measurement Facility
mV	Millivolt
NA or N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NASTRAN	Finite Element Modeling Program
NIST	National Institute of Standards and Technology
Nom	Nominal
nT	Nanotesla
OASPL	Overall Sound Pressure Level
Ohm	Unit of Resistance

Abbreviation Symbol	Translation
Oz	Ounce
Pa	Pascal
PC	Personal Computer
PCM	Pulse Code Modulation
pH	Measure of Acidity
P/L	Payload
PLC	Programmable Logic Controller
POI	Product of Inertia
PRT	Platinum Resistance Thermometer
PSD	Power Spectral Density
Psi	Pounds per Square Inch
Psig	Pounds per Square Inch Gauge
QCM	Poly Vinyl Chloride
Rad	Quartz Crystal Microbalance
Rad/sec	Radian
RF	Radians Per Second
RFI	Radio Frequency
RGA	Radio Frequency Interface
RH	Residual Gas Analyzer
RM or Rm	Relative Humidity
RMS or rms	Room
RPD	Root-Mean-Squared
RPM or rpm	Revolutions per Minute
RPS or rps	Revolutions per Second
RTV	Room Temperature Vulcanizer
S	Second
SC	Solar Constant
SCA	Spacecraft Checkout Area
SCADA	Supervisory Control and Data Acquisition
Scfm	Standard Cubic Feet per Minute
SES	Space Environment Simulator
SMTF	Spacecraft Magnetic Test Facility
SPL	Sound Pressure Level
t	Thickness
T	Tesla
T/C	Thermocouple
Temp	temperature
Torr	1/760 of a Standard Atmosphere
TQCM	Thermoelectric Quartz Crystal Microbalance
TVDS	Thermal Vacuum Data System
UD	Unholtz-Dickie
UV	Ultraviolet
V	Volt
VA	Volt Ampere
Vac	Vacuum
Vol	Volume
W or w	Watt
W	Width

APPENDIX – B: METRIC/ENGLISH CONVERSION FACTORS

Convert From:	Translation:	Multiply By:
Amp/centimeter^2	Amp/Inch^2	6.45
Amp/decimeter^2	Amp/ft^2	9.09
Celsius	Fahrenheit	[C x (9/5)] + 32
Centimeter	Inch	0.3937
Centimeter^2	Inch^2	0.155
Centimeter^2/liter	Foot^2/gallon	0.0041
Gram	Ounce	0.0353
Gram	Pound	0.0022
Gram/centimer^2	Ounce/Inch^2	0.228
Gram/liter	Ounce/gallon	0.133
Gram/liter	Troy	0.125
Kilogram	Pound	2.205
Kilogram	Ton	0.0011
Liter	Gallon	0.2642
Meter	Inch	39.37
Meter	Foot	3.281
Meter^2	Foot^2	10.76
Meter^3	Foot^3	35.31
Meter2/liter	Foot^2/gallon	40.82
Micron	Microinch	39.4
Micron	Inch	0.0000394
Micron	Mil	0.0394
Millimeter	Inch	0.0394
Newton	Pound (force)	0.225
Newton-Meter	Inch-Pound (Force)	8.85
Newton-Meter	Foot-Pound	0.7376
Pascal	Pound/inch^2	0.000145
Pascal	Torr	0.0075
Watt	Horsepower	0.00134

Convert From:	Translation:	Multiply By:
Amp/Inch^2	Amp/centimeter^2	0.155
Amp/ft^2	Amp/decimeter^2	0.11
Fahrenheit	Celsius	[F-32] x (5/9)
Inch	Centimeter	2.54
Inch^2	Centimeter^2	6.452
Foot^2/gallon	Centimeter^2/liter	245
Ounce	Gram	28.329
Pound	Gram	453.6
Ounce/Inch^2	Gram/centimer^2	4.39
Ounce/gallon	Gram/liter	7.5
Troy	Gram/liter	8
Pound	Kilogram	0.4536
Ton	Kilogram	907.2
Gallon	Liter	3.785
Inch	Meter	0.0254
Foot	Meter	0.3048
Foot^2	Meter^2	0.0929
Foot^3	Meter^3	0.02832
Foot^2/gallon	Meter2/liter	0.0245
Microinch	Micron	0.0254
Inch	Micron	25400
Mil	Micron	25.4
Inch	Millimeter	25.4
Pound (force)	Newton	4.45
Inch-Pound (Force)	Newton-Meter	0.113
Foot-Pound	Newton-Meter	1.356
Pound/inch^2	Pascal	6895
Torr	Pascal	133.32
Horsepower	Watt	745.7

APPENDIX – C: DECIMAL PREFIXES

Prefix	Symbol	Factor
Atto	a	10^{-18}
Femto	f	10^{-15}
Pico	p	10^{-12}
Nano	n	10^{-9}
Micro	μ	10^{-6}
Milli	m	10^{-3}
Centi	c	10^{-2}
Deci	d	10^{-1}

Prefix	Symbol	Factor
Deka	da	10^{1}
Hector	h	10^{2}
Kilo	K	10^{3}
Mega	M	10^{6}
Giga	G	10^{9}
Tera	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}