Marshall Space Flight Center Test Capabilities

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The Test Laboratory at NASA's Marshall Space Flight Center has over 50 facilities across 400+ acres inside a secure, fenced facility. The entire Center is located inside the boundaries of Redstone Arsenal, a 40,000 acre military reservation. About 150 Government and 250 contractor personnel operate facilities capable of all types of propulsion and structural testing, from small components to engine systems and structural strength, structural dynamic and environmental testing. We have tremendous engineering expertise in research, evaluation, analysis, design and development, and test of space transportation systems, subsystems, and components.

Nomenclature

BTU	=	British Thermal Unit, measure of heat
CH_4	=	methane
ET	=	Space Shuttle External Tank
g	=	acceleration of gravity, 32 ft/s^2
GH_2	=	gaseous hydrogen
GHe	=	gaseous helium
GN_2	=	gaseous nitrogen
GOX	=	gaseous oxygen
gpm	=	gallons/minute, measure of volume flow rate
lbf	=	pounds force, measure of force
lbm	=	pounds mass
lb/s	=	pounds/s, measure of mass flow rate
LCH_4	=	liquid methane
LH_2	=	liquid hydrogen
LOX	=	liquid oxygen
P_0	=	inlet pressure
Ppm	=	parts per million, measure of concentration
psia	=	lb/in^2 absolute
psig	=	lb/in^2 gage, pressure referenced to atmosphere
RP-1	=	Rocket Propellant 1, refined kerosene
rpm	=	revolutions per minute
sps	=	samples per second
SRS	=	Shock Response Spectrum, impulse response, measured in g's
T_0	=	inlet temperature
TPS	=	Thermal Protection System
W	=	watts, measure of energy

I. Introduction

THE Test Laboratory at NASA's Marshall Space Flight Center (MSFC) has existed as long as the Center; in fact, the oldest facilities were built by the U.S. Army Ballistic Missile Agency and were in existence before NASA was created. Marshall's test capability has been and remains a critical national asset. While many fascinating papers could be written about the history of these facilities, this paper focuses on the existing capabilities relevant to the current NASA mission.

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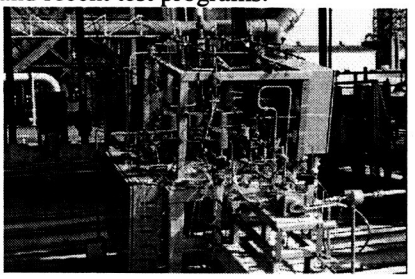
II. Major Facilities and Capabilities

The test facilities at Marshall Space Flight Center are physically located in four areas, known as the East, West, and North Test Areas, and the Structural and Environmental Test Area. For the purposes of this paper they are classified by type of facility and test supported, rather than geographically. There are four major classes of facilities: Propulsion test facilities; Structural test facilities; Environmental test facilities; and Wind Tunnel facilities.

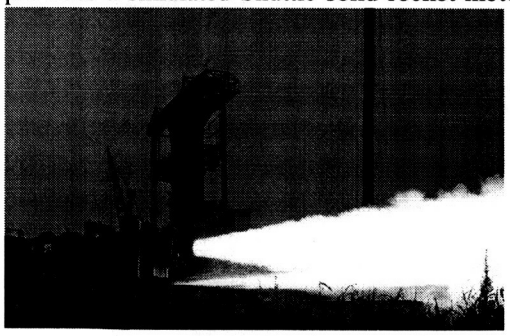
A. Propulsion test facilities

The propulsion test facilities at MSFC are used for testing of sub-scale injectors, injector elements, thrusters, gas generators, turbopumps, igniters, oxygen and hydrogen cold flow components, solid and hybrid motor propellants and materials, hot gas material characterization, and engine systems using liquid hydrogen, methane, and kerosene. The remainder of this paper details these facilities, their salient characteristics, and recent test programs.



The **Advanced Fuels Facility** is a multi-propellant test bed used for comparison testing of exotic hydrocarbon fuels with a baseline fuel, testing of subscale combustion devices, and new technologies such as the laser ignition of RP-1. Capabilities include GN_2, GH_2, GHe, RP-1, Missile Grade Air, a Thrust Measurement system, and laser ignition and diagnostics systems. The Advanced Fuels skid can accommodate small combustion devices about 1-ft by 1-ft by 2-ft and up to 1,000 pounds thrust on the thrust table. Devices can be tested using GOX, GH_2, RP-1, and other hydrocarbon fuels with conventional or laser ignition devices. For fuels comparison testing, two nine-gallon fuel tanks rated at 750 psig are used. The fuel flow rate is 0.5 lb/s. Combustion is initiated using RP-1, and then the tanks are switched while the engine is firing for real-time performance comparison of an alternative fuel with RP-1.

The **Solid Propulsion Test Facility** has two positions, horizontal and vertical, for testing 48-inch diameter solid rocket motors to 100,000 pounds thrust vertically inverted (nozzle up) and 24-inch diameter solid rocket motors to 172,000 pounds thrust horizontally. This facility provides a simulated Shuttle solid rocket motor combustion environment to evaluate performance data, solid rocket motor internal case instrumentation, non-asbestos insulation materials, nozzle designs, materials, and new inspection techniques such as Real-Time Radiography. The Solid Propulsion Test Facility is currently being used to support Space Shuttle Reusable Solid Rocket Motor tests using the 24-inch and 48-inch solid rocket motors.



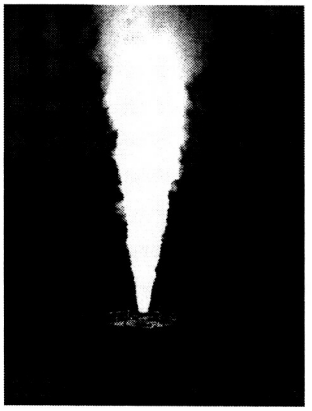
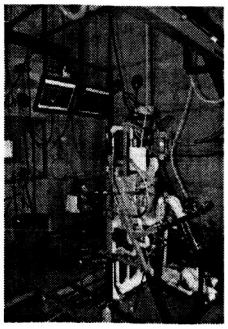
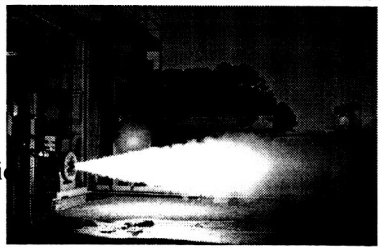


Table 1. Solid Propulsion Test Facility Capabilities	
GN_2	1-inch line, 4,200 psig
Missile-Grade Air	1-inch line, 3,500 psig
Industrial water	150 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

The **Test Cells** are used for up to 5000 pounds thrust solid and hybrid test articles. The test cells are a group of 11 adjacent reinforced-concrete, blast-resistant positions measuring 15 feet wide by 15 feet deep by 10 feet high that have the pressurizing gases and propellants for testing scale model combustion devices and rocket engines. The cells are less expensive to run than other facilities due to the small amounts of propellant required to perform tests. Active positions are now

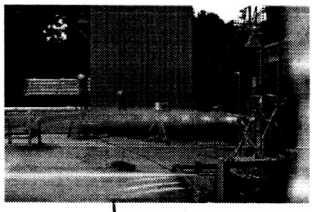




involved in small scale Shuttle solid motor and External Tank foam environment generation for materials and instrumentation evaluation and also support real-time radiography of solid rocket motor composite nozzles.

Table 2. Test Cells Facility Capabilities	
GN_2	1-inch line, 4,200 psig
Missile-Grade Air	1-inch line, 3,500 psig
Industrial water	150 psig
GOX	Tube trailer, 236 ft^3 at 2,400 psig
GHe	Tube trailer, 238 ft^3 at 4,500 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

Test Facility 115 is a multipurpose, multi-position facility capable of testing small or subscale engine systems and medium pressure, small flow rate combustion devices. The facility's compact size makes it ideal for testing subscale components. It was recently used by an in-house MSFC combustion component development program known as the Modular Combustor Test Article Staged Combustion Injector Technology test.



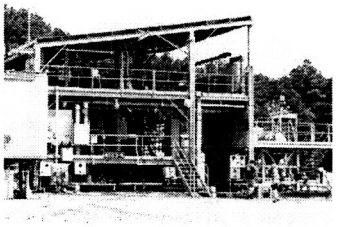


Table 3. Test Facility 115 Capabilities	
LH_2/CH_4	2,200 gallons at 1,500 psig 500 gallons at 3,000 psig
CH_4/RP-1	20 gallons at 3,000 psig
LH_2 flow	1.5 lb/s
RP-1 flow	7 lb/s
LCH_4 flow	4.5 lb/s
LOX	500 gallons at 3,000 psig, future 25,000 gallons
LOX flow	8 lb/s
GOX	Tube trailer, 236 ft^3 at 2,400 psig
GOX/LOX Heat Exchanger	3 lb/s
GH_2	Tube trailer, 157 ft^3 at 3,800 psig, future 940 ft^3 at 4,100 psig, capable of 5 lb/s
GHe	Tube trailer, 238 ft^3 at 4,500 psig
GN_2	3-inch line, 4,200 psig
Demineralized Water	500 gallons at 3,000 psig, 15 lb/s
Missile-Grade Air	1-inch line, 3,500 psig
Industrial water	150 psig
Hydraulics	10 gpm at 3,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

Test Facility 116 is ideal for testing high-pressure engine system components, turbo pumps, valves, cryogenic propellant system components, and combustion devices to 150,000 pounds thrust. This multi-position stand can run multiple tests simultaneously and also can be used for acoustic environmental simulation tests. There are six

positions at this facility: Turbine Blade Position, Acoustic Model Position (30,000-lb thrust), Turbopump Position, Pre-burner Position (50,000-lb thrust), High-flow Water Position, and the 60,000-lb Thrust Position (upgraded 40K Position). Most recently, Test Facility 116 was used for testing the 50,000 pound thrust RS-88 LOX-Ethanol engine for the Orbital Space Plane Pad Abort Demonstrator test.

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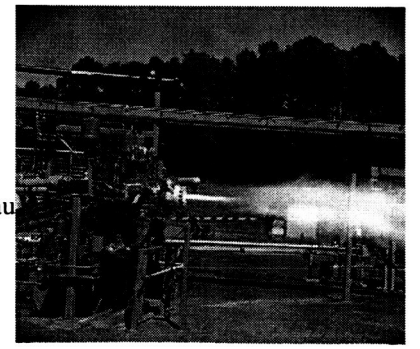
Table 4. Test Facility 116 Capabilities	
LH_2	2,200 gallons at 6,000 psig 2,000 gallons at 8,500 psig
LH_2 flow	60k position: 25 lb/s Pre-burner position: 90 lb/s Turbine Blade position: 3 lb/s
RP-1/High Pressure Water	3,000 gallons at 4,750 psig 3,000 gallons at 2,700 psig
RP-1/High Pressure Water flow	60k position: 100 lb/s Turbopump position: 60 lb/s High-flow position: 7,500 gpm for 11.8 s
LOX	3,000 gallons at 5,250 psig
LOX Storage	28,000 gallons and 14,000 gallons
LOX flow	60k position: 160 lb/s Pre-burner position: 160 lb/s Acoustic Model position: 20 lb/s Turbine Blade position: 10 lb/s Turbopump position: 160 lb/s
GH_2	600 ft^3 at 10,000 psig 1,250 ft^3 at 15,000 psig 1.5 -inch line at 4,400 psig
GH_2 flow	Pre-burner position, 10 lb/s Acoustic Model position, 2 lb/s
GHe	1.5-inch line at 4,200 psig
GN_2	1,250 ft^3 at 10,000 psig 700 ft^3 at 8,000 psig 3-inch line, 4,200 psig
Missile-Grade Air	1.5-inch line, 3,500 psig
Industrial water	150 psig
Hydraulics	50 gpm at 3,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

Test Facility 500 is a six position stand designed for hazardous testing of LH_2, LOX, solid, and hybrid propulsion components and subsystems including combustion devices, propellant pumps, bearings, tanks and valves. The bearing drives are a 500 horsepower diesel engine with a variable-speed transmission to 40,000 RPM for the LOX position and a pressurizing gas (GN_2) with an electro-hydraulic valve controller for the LH_2 position. The six positions at this facility are:



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LH_2/LOX Component Test Position A and Test Position B, the 24-inch Solid/LOX Hybrid Motor Position, the LOX Bearing Test Position, the LH_2 Bearing Test Position, and the Propellant Tank Position. Test Facility 500 is presently being used by KT Engineering of Huntsville, Alabama to test their modular thruster design.

Table 5. Test Facility 500 Capabilities	
LH_2	5,000 gallons at 2,000 psig 36,000 gallons at 100 psig (elevated) 100,000 gallons at 75 psig (inactive)
LH_2 flow	11 lb/s
LN_2	3,000 gallons at 1,000 psig
LN_2 Flow	35 lb/s
LOX	3,000 gallons at 2,000 psig 23,000 gallons at 80 psig (elevated)
LOX Storage	28,000 gallons at 50 psig
LOX flow	70 lb/s
GH_2	3-inch line, at 4,200 psig
GHe	3-inch line, at 4,200 psig
GN_2	3-inch line, 4,200 psig
Missile-Grade Air	1.5-inch line, 3,500 psig
Industrial water	150 psig
Hydraulics	A: 5 gpm at 3,000 psig B: 11 gpm at 3,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

The **Advanced Engine Test Facility** is a 1,000,000 pound thrust LOX/RP-1 and LOX/LH_2 test facility. This two-position, tri-propellant facility is capable of evaluating and characterizing full-up engine and vehicle stage systems in the vertical configuration. Position 1 is configured as a LOX/LH_2 position with the piping interface designed to mate to a Space Shuttle Main Engine with a thrust structure rated for 375,000 pounds. Thrust measurement is available. Position 2 is configured as a LOX/RP-1 position with the piping interface designed to mate to the Atlas propulsion module for testing the Russian RD180 engine with a thrust structure rated for 900,000 pounds. Thrust measurement is available in the vertical direction only in Position 2. The Advanced Engine Test Facility has been used to test a single Space Shuttle Main Engine 66 times. It was also used to hot-fire the Lockheed Martin Atlas RD-180 LOX/RP-1 engine four times. It is presently is a stand-by mode with purges active.

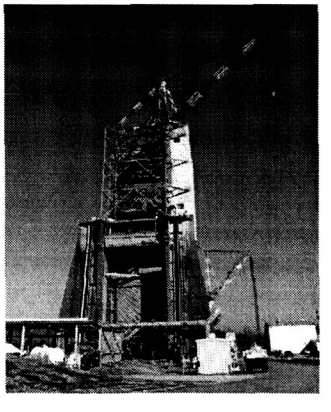

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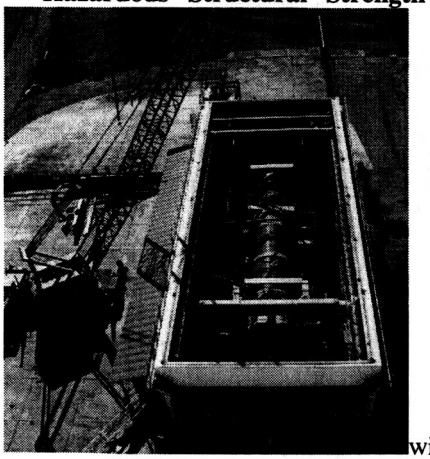
Table 6. Advanced Engine Test Facility Capabilities	
LH_2	Position 1: 75,000 gallons at 50 psig 450,000 gallons at 100 psig storage
LH_2 flow	11 lb/s
RP-1	6,000 gallons at 130 psig 14,000 gallons at 150 psig 20,000 gallons storage
LOX	Position 1: 23,000 gallons at 150 psig Position 2: 12,000 gallons at 130 psig
LOX Storage	78,000 gallons at 100 psig
LOX flow	1,288 lb/s, limited only by 25 ft/s LOX velocity constraint

GH_2	11,400 ft^3 at 3,100 psig
GHe	2,500 ft^3 at 4,200 psig 90 ft^3 at 10,000 psig
GN_2	6.0-inch line, 4,200 psig 3,750 ft^3 at 4,200 psig
Missile-Grade Air	Two 1.5-inch lines, 3,500 psig
Industrial water	Storage of 7,000,000 gallons for firex and deflector cooling
Deflector cooling	200,000 gpm at 150 psig
Firex	110,000 gpm at 150 psig
Hydraulics	Two 15 gpm at 5,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

B. Structural Facilities

Structural Strength Test provides load environments to simulate launch, on-orbit, and landing conditions for development, qualification, acceptance and research testing of space flight hardware. It maintains the capability for instrumentation (strain gages, deflections, loads, pressures, temperature, and humidity), data acquisition (4,600 channels), pressure control (ambient and cryogenic), flow control (pneumatic, ambient liquids, cryogenic LN_2, LHe, and LH_2), temperature control and mechanical load control.

Hazardous Structural Strength Test facility (Building 4572) accommodates full scale test articles



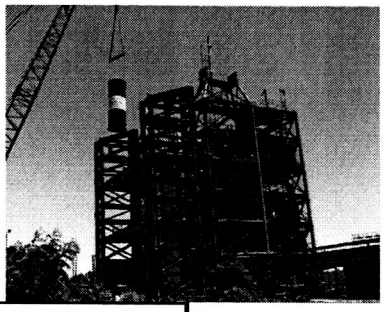
with high loads and pressures. 4,600 instrumentation channels are available, along with a large inventory of load cells, pressure sensors, and displacement sensors.

Table 7. Hazardous Structural Test Facility, Building 4572	
Test Bay dimensions	40-ft x 94-ft x 48-ft
Floor	Reinforced concrete 5-ft thick
Roof	Removable for test article installation and removal
End walls	12-ft thick concrete. Capable of reacting loads of 2,500,000 lbf
Cranes	Bridge crane with two independent trolleys rated at 5,000 lb each

Cryogenic Structural Test Facility (Building 4699) can be used to evaluate the structural integrity of tanks and other propulsion components under a variety of conditions using compression, sheer, and tension loads, while filled

with gases or cryogens. Inside the facility is a 30-ft by 30-ft concrete test pad measuring 2 ft thick. The Cryogenic Structural Test Facility most recently was used for the Northrop-Grumman composite hydrogen tank tests.

Table 8. Cryogenic Structural Test Facility Capabilities



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LH_2	225,000 gallons at 100 psig storage 28,000 gallons at 50 psig storage
GH_2	3-inch line, 3,100 psig
GHe	1-inch line, 4,200 psig
GN_2	3-inch line, 4,200 psig
Missile-Grade Air	1-inch line, 3,500 psig
Industrial water	150 psig
Hydraulics	10 gpm at 3,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

Structural Strength Test High Bay Facility consists of two adjacent high-bay areas inside Building 4619. They feature 4,600 channels of data acquisition; support for four large scale tests in parallel; engineering data computed in background during acquisition; test-generated 3D Finite Element Model displays; and stress analyst stations to support real time monitoring and plotting. The following two tables summarize the capabilities.

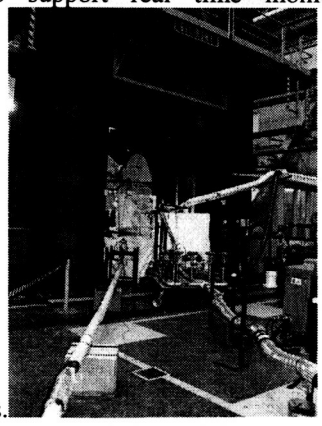

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Table 9. Structural Strength Test East High-Bay Facility	
Access door dimensions	40-ft x 40-ft
Reaction floor dimensions	64-ft x 154-ft, 11-ft thick
Tie-downs	Load plates (each containing four tie-downs) symmetrically affixed on 10-ft centers. Each plate capable of 340 klbf in tension and 44 klbf in shear.

Cranes	Two 25-ton bridge cranes each with one 25-ton trolley. Each trolley has independent 20-ton and 5-ton hooks; 80-ft hook height
Test article height	Up to 75-ft
Universal Test Machines	Tensile and compressive loads 120 klbf, 260 klbf, 2 Mlbf and 3 Mlbf
Modular test frames	Three frames accommodate loads of 10, 50, and 100 klbf. Frame volumes: 6-ft cube, 10-ft cube, and 20-ft cube
Load application	Hydraulic actuators (1-1/8-inch to 33-inch bore) Closed loop servo load control: 1, 128 channel system or 2, 64 channel systems; 1, 48 channel system; 2, 32 channel systems Closed loop pressurization system: Hydrostatic to 1,000 psig; pneumatic to 5,000 psig

Table 10. Structural Strength Test Central High-Bay Facility	
Access door dimensions	57-ft x 75-ft
Reaction floor dimensions	81-ft x 82-ft, 10-ft thick
Tie-downs	On 18-inch centers, each capable of 111.3 klbf in tension and 19.4 klbf in shear. Total shear reaction capability 2.4 Mlbf
Crosshead	Positioned from 40-ft to 115-ft height in 5.5-inch increments. Reaction capability 30 Mlbf.
Cranes	Two 30-ton bridge cranes each with two 15-ton single hook trolleys.
Test Article height	Up to 100-ft high by 54-ft diameter

Structural Dynamics Modal test provides experimentally determined frequency, damping and mode shape (eigenvalues and eigenvectors) of flight structural systems and components, DC-35,000 Hz. Provides experimental data to verify and correlate analytical finite element models of flight hardware. The fixed base facility accommodates shuttle cargo bay payloads up to 210,000 lbm per side, fixed to bedrock. Full-field holography of

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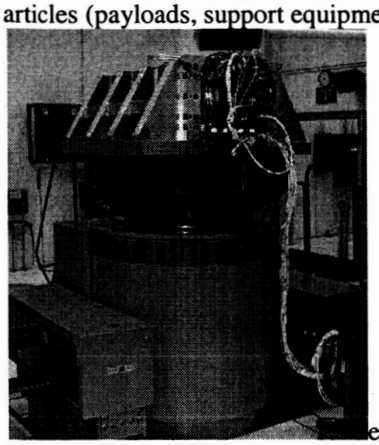
displacements (DC-35,000 Hz) with 125-nm displacement resolution is available. The component/small channel capability provides both fixed-base boundaries and free-free boundaries. The scanning laser vibrometer allows non-contact measurements to characterize the dynamics of inflatable systems. The segmented adaptive optics lab (36 segment primary mirror) has all segments actively controlled (tip & tilt to 200 Hz, piston to 90 Hz) and features a Hartmann-Shack wave-front sensor with interferometer resolution to 632 nm. The facility also includes a micro-gravity vibration isolation lab for vibration isolation actuator development

and test and for micro-gravity payload/support equipment vibration and acoustic emission characterization over the International Space Station required range of 0.01-300 Hz.

Structural Dynamics Vibration Test is used to verify design concepts subject to flight vehicle dynamic loads (launch, on-orbit, and landing) and to certify flight articles (payloads, support equipment, and components) for flight vehicle dynamic loads. Capabilities include eight  electromagnetic shakers (up to 40,000 lbf) that can accommodate a test article up to 5 ft^2. Signal conditioning and acquisition is provided by two systems with 32 channels of response and control data and two systems with 16 channels of response and control data. Modes of vibration spectra available include sine and random, sine on random and random on random, and classical shock and shock response spectrum (SRS).

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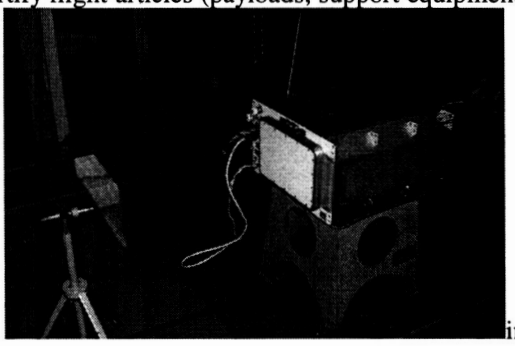
Structural Dynamics Vibroacoustics test is used to verify design concepts subject to flight vehicle dynamic loads (launch, on-orbit, and landing), to certify flight articles (payloads, support equipment, and components) for flight vehicle dynamic loads, and to verify and certify flight articles (payloads, support equipment and components) meet acoustic emission requirements. Capabilities  include providing a diffuse field environment to 165 dB and progressive waves to 170 dB with transmissibility ranging from reverberation to anechoic. Excitation control is provided by eight microphone channels. Acoustic excitation is available up to 200 kW. The facility can accommodate a test article up to 500 ft^3 through 8-ft by 8-ft access doors. The anechoic chamber is quieter than NC-40 requirements and allows sound pressure and sound power measurements.

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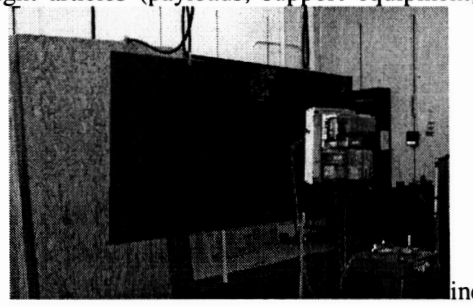
Structural Dynamics Pyrotechnic Shock test is used to verify design concepts subject to flight vehicle dynamic loads (launch, on-orbit, and landing), and to certify flight articles (payloads, support equipment, and components) for flight vehicle dynamic loads. Capabilities  include pyrotechnic excitation sources that generate up to 30,000 g's SRS and 20,000 Hz. Instrumentation includes accelerometers capable of up to 50,000 g's. Test articles up to 500 ft^3 can be accommodated. Signal conditioning and data acquisition is provided by a 16-channel system. Time and Shock Response Spectrum analysis is provided.

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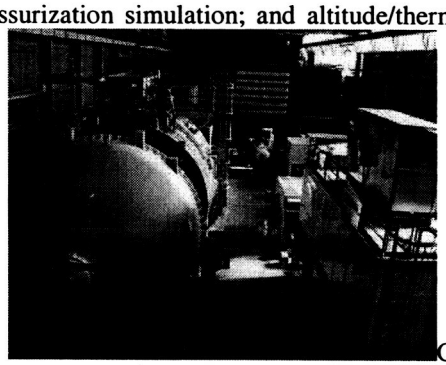
C. Environmental Test Facilities

The **Environmental Test Facility** in Building 4619 provides space thermal vacuum simulation environments for development, qualification, acceptance and research testing of space flight hardware. The facility is located in the West High Bay, a 70-ft by 150-ft space with a 24-ft x 35-ft access door and two 20-ft x 30-ft access doors. The 70-ft by 150-ft concrete floor is ten feet thick. The facility features two overhead bridge cranes with dual independent trolley hooks, one with 20,000 pound capacity and one with 6,000 pound capacity. Hook height is 80-ft. The Environmental Test Facility provides the following test capabilities: thermal vacuum; vacuum bakeout; optical cleanliness vacuum bakeout; life-cycle testing; launch depressurization simulation; and altitude/thermal/humidity



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testing. Test Facilities include 14 Thermal Vacuum Test Chambers; 5 Thermal Humidity Test Chambers; 1 Thermal Altitude Chamber; 1 Class 10K Clean Room; and 1 Class 100K Clean Room. The facility performs 270–340 Tests and Test Series per year. The following chart shows the various chambers and their salient characteristics.

CHAMBER	PRIMARY USE	VACUUM PRESSURES *	TEMPERATURES	THERMAL CONDITIONING	DIMENSIONS
V1	Optical Cleanliness	5×10^{-7} torr	Ambient to 180 °C	Infrared Lamps	4 ft dia. × 7 ft
V2	Optical Cleanliness	5×10^{-8} torr	Ambient to 180 °C	Infrared Lamps	4 ft dia. × 10 ft
V3	Life Cycle	5×10^{-8} torr	−100 to 100 °C	Infrared Lamps, LN_2	4 ft dia. × 10 ft
V4 & V8	Vacuum Bakeout	1×10^{-6} torr	Ambient to 175 °C	Infrared Lamps	2 ft dia. × 2.5 ft
V5	Vacuum Bakeout	1×10^{-6} torr	−170 to 150 °C	Infrared Lamps, LN_2	3 ft dia. × 4 ft
V6	Vacuum Bakeout	1×10^{-7} torr	−170 to 150 °C	Infrared Lamps, LN_2	3 ft dia. × 4'
BUNDLE	Thermal Vacuum	1×10^{-7} torr	Ambient to 180 °C	Infrared Lamps	3 ft dia. × 5v
V7	Optical Cleanliness	5×10^{-7} torr	−170 to 150 °C	Infrared Lamps, LN_2	8 ft dia. × 10 ft
V9	Launch Depress	1×10^{-6} torr	Ambient	Infrared Lamps, LN_2	4 ft dia. × 7 ft
V10	Life Cycle	5×10^{-8} torr	Ambient to 100 °C	Infrared Lamps, LN_2	1.5 ft dia. × 1.5 ft
V11	Thermal Vacuum	1×10^{-6} torr	Ambient to 180 °C	Infrared Lamps, LN_2	8 ft dia. × 10 ft
V12	Thermal Vacuum	1×10^{-6} torr	−100 to 100 °C	Infrared Lamps, LN_2	1.5 ft dia. × 2 ft
Sunspot	Thermal Vacuum	1×10^{-6} torr	−170 to 200 °C	Infrared Lamps, LN_2	10 ft dia. × 12 ft
V20	Thermal Vacuum	1×10^{-6} torr	−170 to 200 °C	Infrared Lamps, LN_2	20 ft dia. × 27 ft
TH–1, TH–2, TH–3	Thermal Humidity	Ambient	−70 to 190 °C	Electrical Resistive, Refrigeration	4 ft × 4 ft × 4 ft
TH–4 & TH–8	Thermal Humidity	Ambient	−70 to 160 °C	Electrical Resistive, Refrigeration	4 ft × 4 ft × 4 ft
TA–1	Thermal Altitude	Ambient to 100,000 ft	−70 to 190 °C	Electrical Resistive, Refrigeration	4 ft × 4 ft × 4 ft

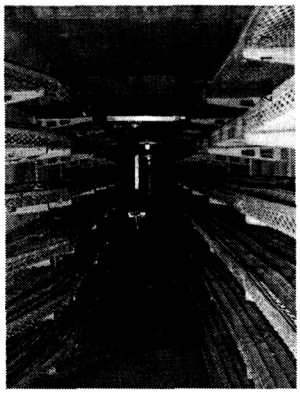
The Environmental Test Facilities have recently been used for External Tank Development Flight Instrumentation Relay Assembly Thermal Cycle Qualification and Acceptance Tests; International Space Station Control Moment Gyro Flight Support Equipment Adjustable Shims Thermal Vacuum Tests; and Reinforced Carbon-Carbon Crack Repair Deliquification tests.

The **Hydrogen Cold Flow Facility** is a low-pressure, high-flow-rate closed loop cold flow test facility with two 225,000 gallon hydrogen storage tanks. It is a multi-purpose facility for low pressure system tests of hydrogen engine and subsystem components. Liquid hydrogen can flow from one 225,000-gallon storage tank through the test article into a second 225,000-gallon storage tank at a rate of 1,800 gallons per minute. The rate can be increased to

5,000 gallons per minute as needed. The facility also can run tests using gaseous nitrogen, helium, and missile grade air. The facility can accommodate test articles up to 20-ft by 20-ft by 15-ft under roof or even larger sizes on the adjoining apron. The Hydrogen Cold Flow Facility has most recently been used by the Space Shuttle Main Engine Liquid Air Insulation tests as part of the Return to Flight of the Space Shuttle.

Table 11. Hydrogen Cold Flow Facility Capabilities	
LH_2	450,000 gallons at 50 psig
LH_2 flow	Up to 5,000 gallons per minute
GH_2	1-inch line, at 3,100 psig
GHe	1-inch line, at 4,200 psig
GN_2	1-inch line, 1,500 psig
Missile-Grade Air	1-inch line, 500 psig
Industrial water	80 psig
Hydraulics	20 gpm at 3,000 psig
Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

The **Optical Propagation Tunnel Facility** is a 330-meter still-air line-of-sight tunnel for testing optical systems, sensors and components. It is 4-ft wide and can be bridged by a customer-supplied trolley. It provides an enclosed, still-air, controlled access space for guidance, navigation, and control simulations and tests of automated rendezvous and docking systems with flight-like degrees of freedom. The Optical Propagation Tunnel Facility has been used by both the Advanced Video Guidance Sensor Tests and the Demonstrator for Autonomous Rendezvous Technology.



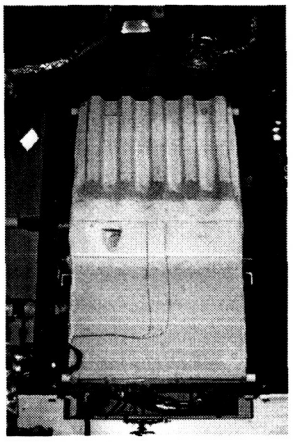
Test Facility 300 has three vacuum chamber facilities used to conduct hazardous tests using cryogens and heat loads. Active test positions at Test Facility 300 include a 12 foot horizontal chamber, a 15 foot vertical chamber and a 20 foot vertical chamber. The dome section of each vacuum chamber is removable to allow installation of large test articles. Each vacuum chamber can be operated separately allowing independent test projects to be run simultaneously.

Table 12. Test Facility 300 Vacuum Chambers			
	12 ft vacuum chamber	**15 ft vacuum chamber**	**20 ft vacuum chamber**
Dimensions	12 ft diameter by 15 ft long carbon steel chamber	15 ft diameter by 25 ft tall stainless steel chamber	20 ft diameter by 35 ft tall stainless steel chamber
Vacuum level	10^{-3} torr	10^{-3} torr (future 10^{-6} torr)	10^{-8} torr
Radiant heat load	20 BTU/ft^2-s	None	none
Rapid pump-down	High pressure GN_2 ejector	None	High pressure GN_2 ejector
Residual Gas Analyzer	None	None	Yes

Table 13. Test Facility 300 Facility Capabilities	
LH_2	Offload to test articles from government-owned tankers, capacity 12,000 gallons
GH_2	3-inch line, at 4,200 psig
GHe	1.5-inch line, at 4,200 psig
GN_2	3-inch line, 4,200 psig
LN_2 storage	13,500 gallons at 50 psig
Missile-Grade Air	1.5-inch line, 3,500 psig
Industrial water	150 psig
Hydraulics	10 gpm at 3,000 psig

Low speed digital data	200 sps
High speed digital data	250,000 sps
Real-time video with sound	30 frames per second
High speed film camera	400 frames per second
High speed digital video	1,000 frames per second for 52 seconds

Test Facility 300 has most recently been used for External Tank Foam testing in support of the Return to Flight of the Space Shuttle. The 12-ft vacuum chamber was used to simulate the ascent pressure and temperature profiles seen on the External Tank. Concurrent with the External Tank panel testing, the 20-ft vacuum chamber was used for zero boil-off tests with the Multipurpose Hydrogen Test Bed as part of an MSFC in-house cryogenic management program.



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D. Wind Tunnel Facilities

The **Aerodynamic Research Facility** is an intermittent tri-sonic blow down tunnel, operating from pressure storage to vacuum or atmospheric exhaust. The test section measures 14-inch by 14-inch with interchangeable sections. The transonic section provides for Mach numbers of 0.2-1.3, 1.46, and 1.96. The supersonic section provides for Mach 2.74 - 4.96. The test section size (H x W x L) is 14-inch x 14-inch x 24-inch.

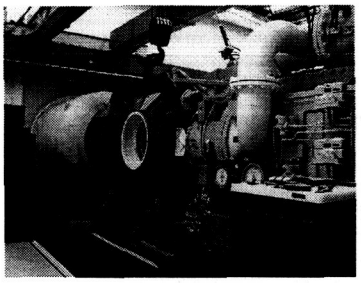

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Table 14. Aerodynamic Research Facility Capability

Intermittent blow-down to atmosphere or vacuum		
Test Section Size: (H x W x L)	14 x 14 x 24 inches	
Reynolds Number:	1 to 18 million per foot	
Stagnation Pressure:	<22 to 80 psia	
Dynamic Pressure:	2 to 20 psia	
Stagnation Temperature:	Ambient to 200 °F; normally 100 °F	
Air Storage:	6,000 ft^3 at 400 psia and 100 °F	
Vacuum Storage:	42,000 ft^3 at 0.1 psia	
Run Rate:	15 to 20 runs per 8-hour shift	
Angle of Attack:	-10 to +10 degrees (90 degrees with offset sting)	
Interchangeable test sections		
Test section	Transonic	Supersonic
Nozzle	3-Fixed contour blocks	Variable contour plates
Mach Range	0.2-1.3, 1.46, 1.96	2.74-4.96
Run Time	60 to 90 seconds	30 to 40 seconds
Recharge Time	10 to 15 minutes	15 to 20 minutes
Data Acquisition	200 channel pressure scanning system; forces and moments measured by an internal, 6 component, strain gage balance	
Flow Visualization	Schlieren, Shadowgraphs, Oil Flows, and High speed video	

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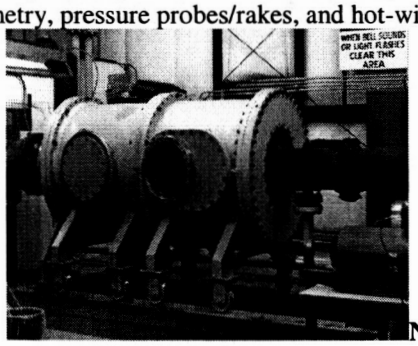
The **Injector Test Rig** is a pressure flow facility used to evaluate performance of injectors. Two flow systems deliver simulated, non-reactive propellants (water representing LOX and silicon oil representing fuel). Flow delivery is via pressurized supply vessels and throttled by flow control valves. There is off-line de-aeration capability along with injectant filtration to 20 microns. Determination of spray mass distribution and mixture ratio is possible using a patternator to capture and measure injector discharge. An optical system is used to accurately measure propellant distribution. Injectant pressures to 275 psig and flow rates to 15 gpm on each delivery system are possible. Instrumentation consists of a flow system and model pressures, flow rates, and propellant simulant temperature. Spray mass distribution is measured across a 4-ft by 4-ft collection grid into 625 discrete collection tubes.

The **Calibration Wind Tunnel Facility** is an open-jet type, 6-inch x 6-inch inlet test section with a maximum flow velocity of 350 ft/s. The facility is used to calibrate three- and five-hole flow direction probes using an automated calibration process that positions the probe over ±30 degrees in the pitch and yaw planes, sets the velocity in the test section, and prints out the data in summary form for the user.

The **Solid Rocket Motor Airflow Facility** is a high pressure blow-down system with 1,900 psia storage vessel supply and atmospheric discharge after passing through a Solid Rocket Motor test article. The facility provides the full-scale Mach number and Reynolds number for 10-percent scale advanced Solid Rocket Motor models. The facility can provide bore flow or mass injection through porous walls and investigate affects of gimbaling submerged nozzles, slot/port interactions, and other flow disturbances on internal flow. The facility provides an inlet pressure range of 600 to 1200 psia and a mass flow range of 20 to 320 lb/s. Test durations can run from 30 to 300 seconds. Instrumentation includes a sub-critical mass flow venturi meter, 150 channel electronic pressure scanning system, 240 channel low-level voltage input data system (temperatures, strains), and 28 analog tape high frequency channels (pressures, accelerometers, strains). Additionally, there is specialized instrumentation for Laser Doppler Velocimetry, pressure probes/rakes, and hot-wire measurements.



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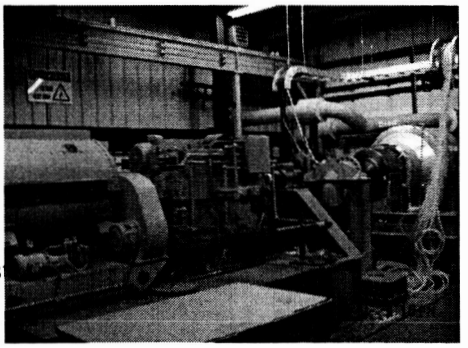
The **Nozzle Test Facility** is an air/nitrogen blow-down facility used to evaluate the performance of nozzles with exit diameters up to ten inches. It features a heated core flow supply, variable test chamber pressure using a two-stage ejector system, and thrust and side force components measurements. Nozzle core flow is 8 lb/s @ 25 to 350 psia and up to 350 °F. The test chamber pressure can range from atmospheric to 0.05 psia with run times of two to three minutes. Instrumentation consists of steady and unsteady pressure measurements, test cabin pressure and temperature, up to 50 model pressures, calibrated load cells to measure thrust and side forces, a calibrated venturi for nozzle mass flow, and nozzle exit flows visualized with Schlieren.

The **Air Flow Turbine Test Equipment** facility is a blow-down system from 420 psia supply to atmosphere or vacuum. It features a stainless steel tunnel with two 6,000 ft^3 storage tanks, closed-loop control of inlet P_o and T_o, pressure ratio, and shaft speed. Inlet flow is conditioned with a wide-angle diffuser, a honeycomb flow straightener, screens, and sine law contraction. It also features a torque meter, gearbox, and 600 hp DC dynamometer for power measurement and



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absorption. Air temperature control is provided by in-line stainless steel tube bundles heated by an off-line electric heater system. A 100-channel slip ring is used for on-rotor measurement.

Table 15. Air Flow Turbine Test Equipment Facility Capability	
Blow-down from 420 psia to atmosphere or vacuum	
Shaft speed range	+/-14,000 rpm
Inlet Pressure range	30 to 300 psia
Exit Pressure range	Atmosphere to 0.05 psia
Inlet Temperature range	530 to 830 °R
Torque range	+/-1000 ft-lb
Power absorption/ motoring capacity	600 hp (900 transient)
Inlet Flow Turbulence Intensity	Approximately 10%
Test Duration	100 seconds to 20 minutes

Instrumentation includes subsonic mass flow venturi meters and sonic critical flow meters; an in-line torque meter with 30 ft-lb, 500 ft-lb, and 1000 ft-lb torque cartridges; a 512 channel electronic pressure scanning system; a 240-channel low-level-voltage-input data system (temperatures, strains), and a 6-channel remote control instrumentation positioning system. Additionally, there is specialized instrumentation for Laser Doppler Velocimetry, high-speed video/film, and hot-wire measurements, and a 100-contact slip ring system for on-rotor unsteady pressure measurements.

The **Water Flow Inducer Test Loop Facility** is a fluid-flow facility constructed of 6-inch and 8-inch diameter stainless steel pipe for conducting suction performance studies of turbopumps. It is a closed-loop, continuous water flow system (about 400 gallons total volume) driven by a 150 horsepower AC motor with 4:1 belt/pulley driveline with a variable speed controller for continuous adjustment of speed. The facility also features a stainless steel 100 gallon inline accumulator/de-aeration tank, a 50 horsepower stainless steel auxiliary centrifugal pump, an air pressurization/vacuum system for loop pressure control, and a heat exchanger for water temperature control.

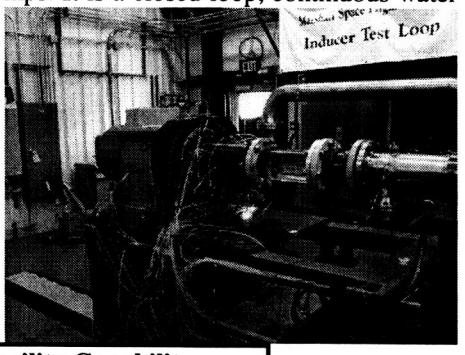

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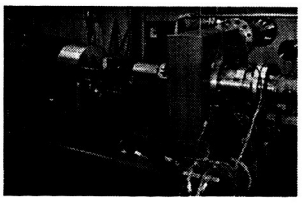
Table 16. Water Flow Inducer Test Loop Facility Capability	
Shaft speed range	1,000 to 7,000 rpm (either direction)
Flow rate range	250 to 3,000 gpm
Water Temperature range	65 to 150 °F
Inlet Pressure range	1 to 100 psia
Discharge Pressure range	Atmosphere to 200 psia
Power/Torque range	100 hp/100 ft-lb max
Power absorption/ motoring capacity	600 hp (900 transient)
De-aeration	Down to 3 ppm

Instrumentation at the Water Flow Inducer Test Loop is a PC-based data acquisition system reading a 6-inch turbine type flow meter, 50 low frequency pressure transducers in the 1 to 65 psia range, 20 low frequency pressure transducers in 1 to 250 psia range, 28 analog tape high frequency channels (pressures, accelerometers, strains), a 100-contact high-speed slip ring system with shaft encoder, specialized instrumentation. (Laser Doppler Velocimetry, high-speed video/film, hot-wire), and a rotating balance to measure 3-forces and 3-moments during operation.

The **Pump Test Equipment Facility** features a closed loop water system with 10,000 gallon reservoir, electrical coil heating in the reservoir, dissolved oxygen monitoring, all-stainless piping with a 12-inch diameter inlet, a flow meter and flow



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control quiet valve, and a torque meter and 350 horsepower drive motor. Instrumentation includes a steady state data system for test article and facility pressure monitoring. Unsteady data is measured in real time and recorded with 1 Hz to 30 kHz bandwidths.

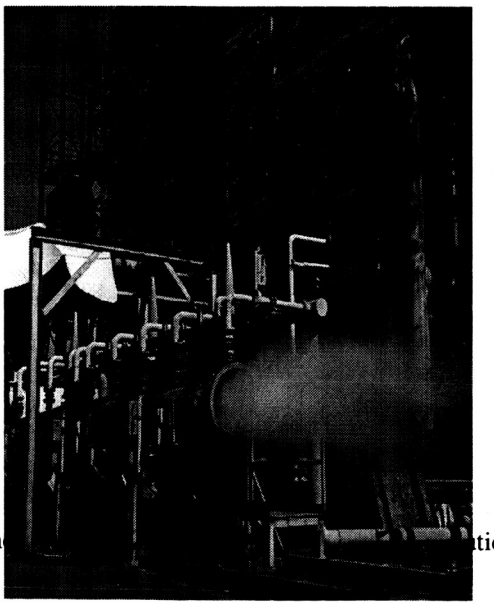
Table 17. Pump Test Equipment Facility Capability	
Shaft speed range	360 to 3,600 rpm
Flow rate range	300 to 3,000 gpm
Inlet Total Pressure range	4-75 psia
Pump Pressure rise	0 to 350 psid
Shaft torque range	0-500 ft-lbf
Drive line power	0-350 hp
Water Temperature	60 °F-160 °F

The **Water Flow Facility** is an open loop, continuous water flow system with all stainless steel construction that accommodates model inlets up to 12 inches in diameter. It features 150 hp, 3000 gpm and 50 hp, 1500 gpm variable speed supply pumps and a 6000 gallon stainless steel supply tank and a 100 hp, 3000 gpm variable speed return pump with a stainless steel, 2,000 gallon discharge dump tank. Water temperature is controlled by a 30 kW water heater. Instrumentation includes 6-inch and 8-inch turbine type flow meters, 150 pressure measurement channels, 28 analog tape high frequency channels (pressures, accelerometers, strains), and specialized instrumentation (Laser Doppler Velocimetry, high-speed video/film, hot-wire).

Table 18. Water Flow Facility Capability	
Flow rate range	50 to 3,000 gpm
Inlet Pressure max	80 psia
Discharge Pressure max	100 psia
Water Temperature	70 °F-100 °F

The **MSFC Materials Environment Test Complex (METCO)** encompasses several test facilities including a Mach 4 combustion-driven wind tunnel (the Hot Gas Facility), a half million pound uniaxial tension test station, a thermal acoustic test station capable of delivering 172 decibels (low and high frequency ranges), a 1.5 million pound biaxial test facility which can be coupled with multiple environments, an arc-heater facility, and multiple radiant heating systems.

The HGF is a GH_2/air combustion-driven wind tunnel used primarily for thermal protection system testing and aero-thermal environments definition. During a test, combustion products are expanded from the combustion chamber through a two dimensional nozzle into a 16 in x 16 in x 40 in long test section. A Mach 4 flow environment is induced and convective heating from 3.5 to 25 BTU/ft^2-s at total temperatures from 1,500 °F to 3,000 °F can be obtained. The tunnel includes a 300 kW radiant heat system, a model insertion system with varying wedge angles, and test section shutter doors to protect the test article from start up and shut down shocks. The radiant heat system provides from 0 to 35 BTU/ft^2-s and can be combined concurrently with the Mach 4 convective heat inputs to make a test facility ideally suited for base heating environments. Radiant-only heating with programmable vacuum is also available. All heating environments can be individually profiled within the parameters of the facility to follow a prescribed flight heating profile. If requested, oxygen may be added to the combustor flow to maintain 21% oxygen. Test environments can also be generated to follow a test article temperature profile. The HGF also offers thermal imaging support to provide customers with real time thermal response and gradients of the test article. Video of test articles can be recorded from 30 to 500 frames per second and 16-mm movie can record up to 10,000 frames per second. Up to 72 channels of instrumentation can be dedicated to each test article; more channels are available upon request. Machine shop capabilities are also available on site. The Hot Gas



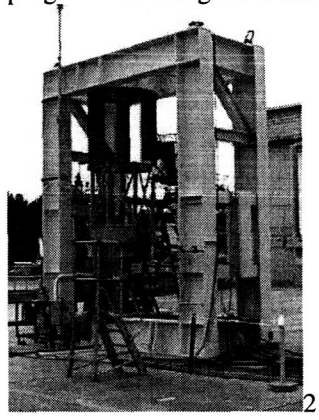
Am tics

Facility is presently being used for Space Shuttle External Tank Foam Return to Flight testing.

The Tensile Test Station offers uniaxial load testing for test articles up to 19-inch x 48-inch. The station load line is currently capable of tension loads up to 500,000 lbf but the frame is capable of up to 1,000,000 lbf. Test articles can be thermally conditioned from -423 °F using liquid helium to +500 °F using gas heaters. Radiant heat and acoustic environments can be added upon request.

The Thermal Acoustic facility was developed in 1997 for the X-33 metallic Thermal Protection System (TPS) and is capable of duplicating the key acoustic loading and surface temperatures environments representative of the X-33 hypersonic flight. The facility was later modified in 1998 to double the acoustic energy in order test the Space Shuttle External Tank (ET) TPS materials. At present, this facility can deliver radiant heat from 0 to 30 BTU/ft^2-s and up to 172 decibels onto a test article up to six feet square. The test article currently used for ET TPS testing has a fully characterized dynamic response which closely matches predicted flight responses. Test articles can be thermally conditioned from -423 °F using liquid helium to +500 °F using gas heaters upon request.

The Combined Environments Biaxial Loads facility is able to induce tension or compression loads of up to 1.5 million pounds in each axis onto a flat or curved test article up to 10 feet square or tanks up to 10 feet in diameter and up to 12 feet high dome-to-dome. The External Tank program has designed a flat test article for this facility



approximately six feet square which results in a uniform 2 to 1 or 1 to 1 strain field which duplicates a pressurized ET side wall or aft dome. The environments from the Thermal Acoustic Facility are then combined with this facility resulting in an ET TPS test facility capable of biaxial loads, acoustics, substrate dynamic response, radiant heat, and substrate cryogenic conditioning.

The Hyper-thermal Convective Test Facility will be used to test the thermal and ablative response of materials used to insulate the Shuttle Solid Rocket Motor nozzle. Gas compositions and temperature conditions which are representative of those encountered in the Reusable Solid Rocket Motor nozzle are simulated in this facility and used to develop and qualify new materials for flight. This facility will also be configured to support Magneto Hydrodynamic propulsion studies.

III. Conclusion

The Propulsion test facilities; Structural test facilities; Environmental test facilities; and Wind Tunnel facilities at Marshall Space Flight Center's Test Laboratory are a unique, highly flexible, adaptable, and capable national resource for ground testing of spacecraft and spacecraft systems.

Acknowledgments

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AIAA JPC Tucson paper
Marshall Space Flight Center Test Capabilities
Figure captions

Figure 1. Advanced Fuels Facility

Figure 2. 24-in Solid Rocket Motor at Solid Propulsion Test Facility
Figure 3. 48-in Solid Rocket Motor at Solid Propulsion Test Facility
Figures 2 & 3 both go with the "Solid Propulsion Test Facility" paragraph

Figure 4. External Tank panel test in Test Cell 101
Figure 5. 11-in GOX Hybrid Solid Rocket Motor test in Test Cell 103
Figures 4 & 5 both go with the "Test Cells" paragraph

Figure 6. Life Cycle Thruster test at Test Facility 115
Figure 7. Test Facility 115
Figures 6&7 both go with the "Test Facility 115" paragraph

Figure 8. RS-88 LOX/Ethanol engine test at Test Facility 116
Figure 9. Reaction Control System Hot-fire test at Test Facility 500
Figure 10. Advanced Engine Test Facility
Figure 11. Hazardous Structural Strength Test Facility
Figure 12. Cryogenic Structural Test Facility

Figure 13. External Tank Panel in Gilmore Load Tester
NEW PICTURE ADDED 5/6

Figure 14. Structural Dynamics Modal Test in Structural Test High Bay
Figure 15. Structural Dynamics Vibration Test
Figure 16. Structural Dynamics Vibroacoustic Test
Figure 17. Structural Dynamics Pyrotechnic Shock Test
Figure 18. Environmental Test Facility
Figure 19. Optical Propagation Tunnel Facility
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Figure 20. External Tank panel test in 12-ft chamber at Test Facility 300
Figure 20 goes with the "Test Facility 300" paragraph

Figure 21. 14-in Trisonic Wind Tunnel at Aerodynamics Research Facility
Figure 22. Injector Test Rig Facility
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Figure 27. Hot Gas Facility at Materials Environment Test Complex
Figure 28. Combined Environments Biaxial Loads Facility