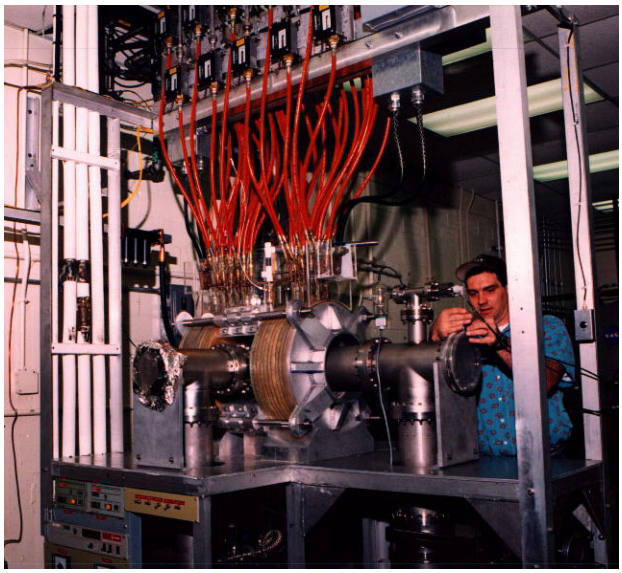
Atomic Oxygen Simulation Facilities

Purpose:

To evaluate the effects of atomic energy on materials to be used in space applications.

MSFC has developed and implemented orbital atomic oxygen simulation facilities based on the physical characteristics of a low earth orbit environment. This capability is used to determine the long term exposure characteristics of objects launched into space.

MSFC employs three methods for achieving the generation of atomic oxygen to stimulate orbital conditions: (1) thermal plasma ashers; (2) out-of-field atomic oxygen drift tube simulators; and (3) 5 eV neutral via the Atomic Oxygen Beam Facility. Each method generates atomic oxygen plasma on the surface of the material under test. The radiation within the plasma represents the spectral line of atomic oxygen. By measuring the magnitude of the spectral line intensity, MSFC can calculate a relative figure-of-merit that is proportional to the strength of interaction between the atomic oxygen and the test material. Each method has different strengths and weaknesses based on cost, safety, purity of the atomic oxygen in the plasma, and the sample's heating characteristics. MSFC's current atomic testing activities involve materials qualification for anodized and alodine aluminum and nickel; KYNAR shrink tubing; apliz; super beta; labels; O-rings; slidewire; targets and teflon overcoats as well as for ProSEDs and NASA/Jet Propulsion Laboratory's flight experiments.



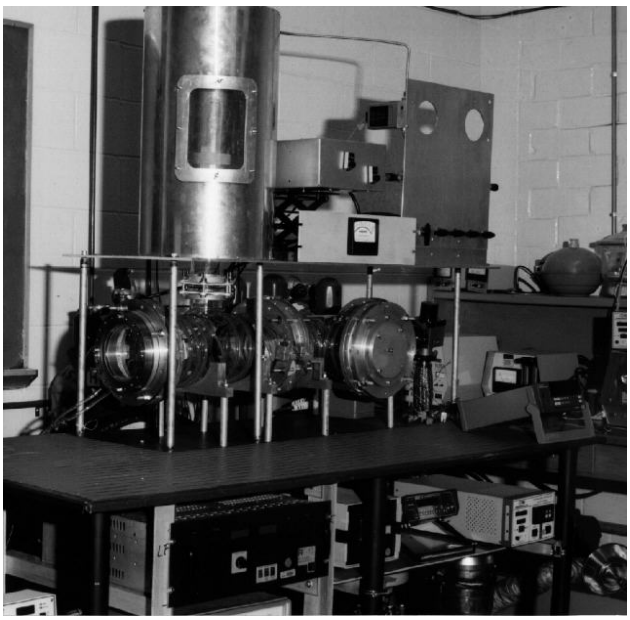
Future activities include continued support for ISS and advanced propulsion systems.

MSFC's orbital oxygen simulation facilities provide a robust means for simulating orbital atomic oxygen in a low earth environment. The Center performs this service for NASA missions as well as vendors and contractors. This unique capability enables the space industry to determine the long term exposure characteristics of objects launched into space.

Atomic Oxygen Simulation Facilities

Atomic Oxygen Drift Tube System

The Atomic Oxygen Drift Tube System generates an atomic oxygen plasma by a 14.7 MHz r-f field, producing up to 5 x 10^{16} atoms/cm^2/sec neutral oxygen atoms of <0.1 eV thermal energy. The samples are exposed outside the r-f field to reduce heating. Near UV or vacuum UV radiation can be added. This facility is located in Building 4711.



Atomic Oxygen Beam Facility

The Atomic Oxygen Beam Facility (AOBF) generates plasma by a 2.45 Ghz, 2kW r-f Field which is confined by a 4 Kgauss magnetic field to increase the flux. Any ions are neutralized by collision with a metal plane. The AOBF is tunable from 3 eV to 20 eV energy and can produce an atomic oxygen flux up to 10^{16} atoms/cm^2/sec with a 5% duty cycle. This facility is located in Building 4711.

Point-of-Contact:

Dr. David Edwards / ED31
(256) 544-4081
david.edwards@msfc.nasa.gov

Particulate Monitoring Facility

Purpose:

To quantitatively measure surface particulate contamination.

Particulate contamination on sensitive surfaces such as optics may produce reductions in performance of these surfaces. This is especially important in ground processing of space-based telescopes where cleaning surfaces directly may introduce contamination or may be too complicated to be allowed. Use of witness mirrors provides a way to monitor particulate contamination buildup without the risk of contamination to the actual surface.

The Materials Department has developed a system to monitor and measure particulate contamination through the use of optical witness mirrors or silicon wafers. Optical samples with various coatings depending on project requirements are placed in the orientation of the surface to be witnessed and exposed to the same environment and processes as the witnessed surface would be.

After exposure the mirror is placed on a robotic microscope stage. Computer controlled movement under the microscope/video imaging system allows images to be taken of the mirror. These images are enhanced to allow sizing and counting of particles. Obscuration changes are calculated and recovered for the mirror. This method is an improvement over manual counting and sizing of particles that are both unreliable and unrepeatable due to the inspector's vision considering lighting conditions and fatigue. This system counts and sizes particles at the 5 micron level and up.

Additional data may be recorded through use of different instruments to provide molecular contamination build-up. Through ellipsometry or other means, the mirror or wafer may be analyzed to determine if the witnessed surface may have been contaminated with molecular contamination.

Point-of-Contact:

DeWitt Burns / ED31
(256) 544-2529
dewitt.burns@msfc.nasa.gov

Surface Cleanliness Inspection Technology Development Facility

Purpose:

To quantitatively measure surface cleanliness with real time, in-process inspection instrumentation.

Cleanliness of critical surfaces is measured in numerous ways. Facilities and instrumentation are available to determine quantitatively contaminant levels on various types of substrates in real item processing environments. Inspection techniques include Fourier transform infrared (FTIR) spectroscopy, optically stimulated electron emission (OSEE) and ultraviolet fluorescence (UVF). Facilities for development of calibration standards for the instrumentation are also available within this department.

FTIR spectroscopic inspection previously available through in-direct evaluation of samples in the laboratory may now be conducted in-process. The Surface Optics Corporation (SOC) 400 reflectometer is a small hand held spectrometer with sensitivity equivalent to that of a laboratory FTIR microscope. Numerous attachments including diffuse and specular reflectance; grazing angle and attenuated total reflectance (ATR) heads insure inspection capability for all substrate types.

OSEE inspection is currently used in the reusable solid rocket motor (RSRM) program for cleanliness inspection prior to adhesive application. The technique is applicable to metal substrates for monitoring any chemical surface changes. This technique is sensitive to low level molecular contaminants that attenuate photoelectric emission from the substrate.

The UVF system is based on imaging UV excited fluorescence from contaminants on the substrate of interest. System features allow detection of contaminants on various metallic and non-metallic substrates.

As a complementary effort to the inspection technologies evaluation a calibration standards development effort was required. This effort developed ultrasonic spray application of repeatable low level contaminant films to substrates of interest. These standards were then used to correlate instrument response to known contaminant levels. Standards have been fabricated for commercial users through Space Act Agreements.

Point-of-Contact:

DeWitt Burns / ED31
(256) 544-2529
dewitt.burns@msfc.nasa.gov

Space Environments Simulation Facility

Purpose:

To enable the testing, evaluation, and qualification of materials for use on external surfaces in space.

Typically, materials are exposed to laboratory simulations of space environments followed by flight experiments when possible. These simulations provide spacecraft designers, engineers, and scientists with valuable information on the behavior of materials in a space environment. The facilities have been used for the space shuttle, the International Space Station, and the Solar X-Ray Imager. They have also been used in postflight analyses of experiments flown in space to determine the changes in optical, mechanical, and electrical properties.

Enhanced Ultraviolet (UV) System

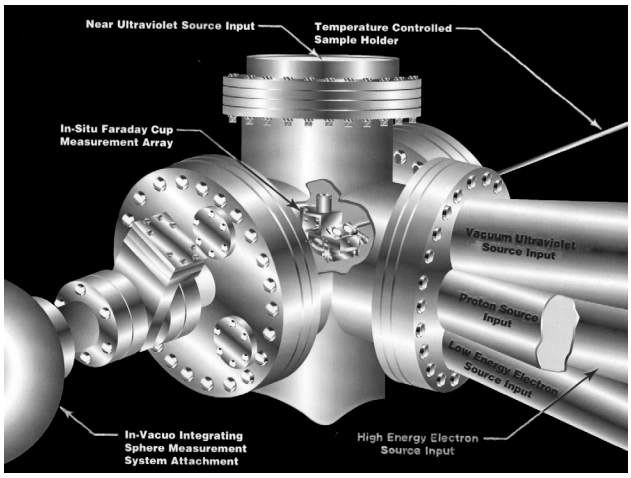
For ultraviolet radiation simulation, the Space Environments and Effects (SEE) team uses a variety of solar simulators, which closely match the solar spectrum from 200 nm to 1500 nm. Infrared radiation is dampened with a water filter to minimize sample heating. The Enhanced UV System can irradiate up to 10 equivalent UV suns in the 200 nm to 400 nm wavelengths. All UV systems operate in a 5 x 10^{-8} torr vacuum.

Combined Environment Effects Test Chamber

Synergistic effects are studied in the Combined Environment Effects Test Chamber. This system consists of a 2.5 MeV electron accelerator, a 1.0 MeV proton accelerator, a 50 KeV electron flood gun, and near ultraviolet (200-400 nm) and vacuum ultraviolet (118-200 nm) solar simulators. In-situ measurement of total integrated reflectance is possible.

The Marshall Magnetic Mirror (M3)

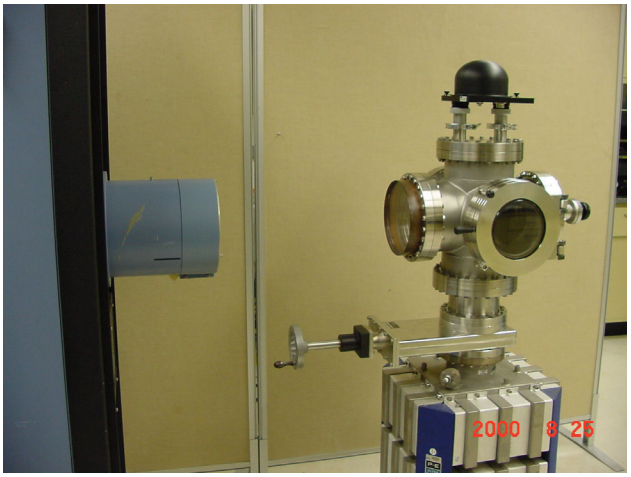
The Marshall Magnetic Mirror (M3) system is an important research tool in the field of advanced propulsion technology. The M3 system is a versatile plasma creation and confinement system that is capable of generating 10 eV (>100,000 °C) plasma with densities up to 1 x 10^{11} particles/cm^3. The basic components of the system include a stainless steel vacuum vessel with multiple diagnostic port locations, a 2 kW microwave source, a flexible magnet coil set rated for 1000 Gauss operation, as well as a high current electron beam source (>100 amps). Brought on-line in 1999, the M3 facility has been investigating the interaction of an electron beam with a magnetically confined plasma. Future experiments will focus on characterizing plasma particle distributions, studying plasma-material interactions, and plasma diagnostic development.

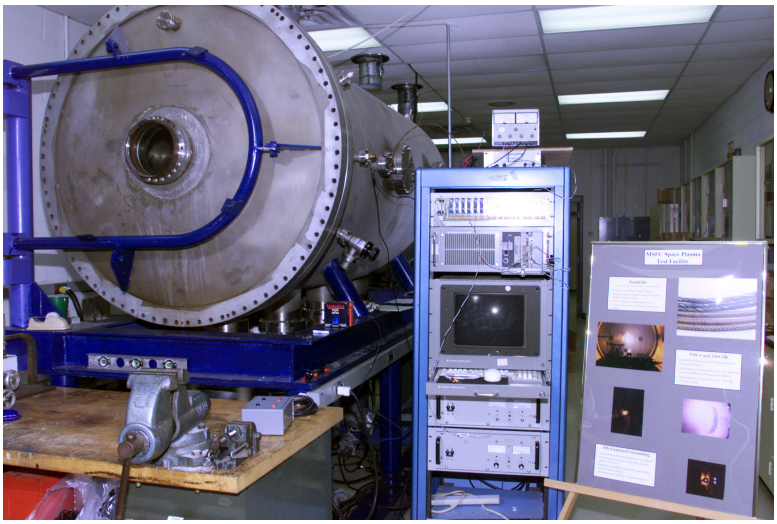


Space Environments Simulation Facility

Plasma Interaction Chamber

The Space Environmental Effects Team operates two large volume vacuum chambers capable of simulating a variety of space plasmas. These chambers can produce plasma densities and energies for orbital environments ranging from Low Earth Orbit (LEO) to Geosynchronous Earth Orbit (GEO). Plasmas are generated using either a hollow cathode source or electron filaments. These systems offer the capability to measure the real-time plasma density and energy. These plasma systems were used to develop the tether material for ProSEDS and perform life testing on the ProSEDS plasma contactor. Recently, these chambers were used to study plasma interaction with the International Space Station (ISS) external coatings.





Photon Pressure Measurement System

Recent interest in using solar sails for spacecraft propulsion and station keeping provided the motivation for the Environmental Effects Group to develop a test system capable of measuring photon pressure. This test system characterizes candidate material for solar sail missions by measuring the photon pressure produced by photon illumination. The test system accepts samples as large as 6 inches in diameter. A solar simulator that has a tunable photon intensity illuminates the candidate material with photons. The resultant pressure on the candidate material is measured.

Point-of-Contact:

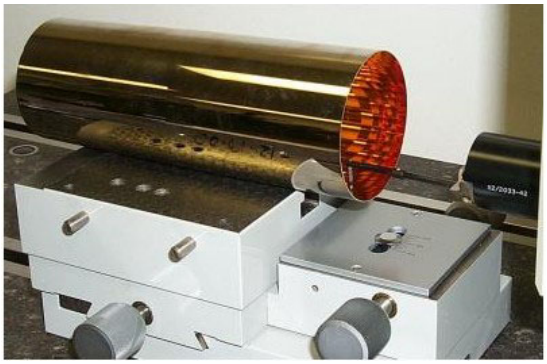
Dr. David Edwards / ED31
(256) 544-4081
david.edwards@msfc.nasa.gov

Precision Metrology Laboratory

Purpose:

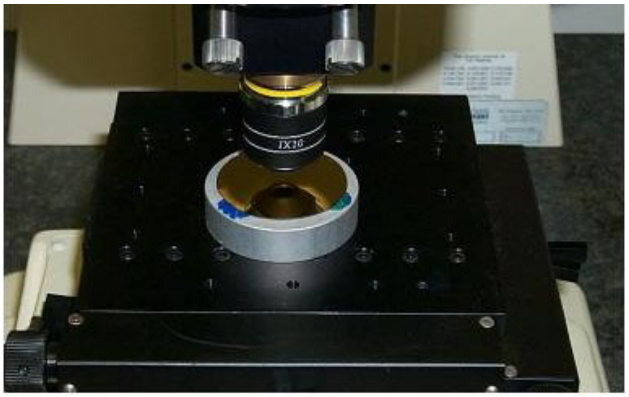
To provide precision metrology for tribology research and related center needs.

The precision metrology lab has its roots from the Army Ballistic Missile Agency days in the 50's and the original team of German rocket scientists. More recently the lab has been used to measure very precise, high-speed, rocket turbopump bearings. With improvements in hybrid ceramic bearing technology, the tolerances and amounts of wear are often extremely minute. Still, with the use of state of the art stylus profilometry and non-contact optical interferometry, wear can be detected in nanometers, and sometimes to angstroms!



To augment such precise quantification of wear, the highest quality, apochromatic microscopes are available to let the experienced researcher visually assess wear surfaces and record them via various media formats including high resolution digital images. Other specialized metrology equipment includes AA "master" gage blocks of chromium carbide and Zerodur®, master ball sets, optical flats, plug and ring gages, screw and gear measuring wires, numerous height gages, master vernier calipers, unique micrometers, optical shadowgraphs, precision electronic levels, autocollimator, surface plates – almost a complete metrology shop! The laboratory is located in a 100k-class clean room in 4711, though higher cleanliness could be readily arranged.

As much of the equipment and expertise is unique to the center, there has been much help provided to other directorate projects in need of precise surface metrology. Examples include measurement of replicated x-ray optics, crystal growth samples, friction stir welding tools, sealing surfaces of International Space Station modules, turbine blade fretting wear, unlubricated polyimide gear wear, to name a few.



Point-of-Contact:

Chip Moore / ED32
(256) 544-2516
chip.moore@msfc.nasa.gov

Computed Tomography System Facility

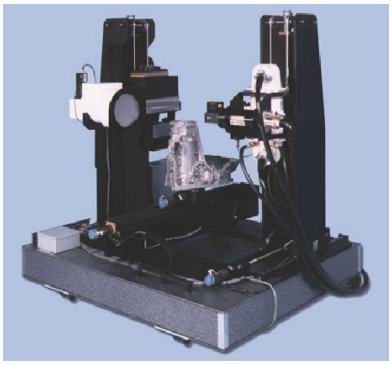
Purpose:

To accurately detect and measure flaws in metallic and composite components including cracks, voids, porosity, and other defects.

MSFC's computed tomography (CT) system produces cross-sectional images of test components. These components can be base material (pre-manufactured) or finished test or flight hardware. The CT system includes two x-ray sources (420 KeV tube and 2 MeV linear accelerator), solid state detectors, a test article movement gantry, and computers that control the system and produce images and allow for user interpretation and analysis.

The CT system generates cross-sections from reconstruction of x-rays that are directed through test components from multiple angles. The resulting images contain a dimensionally accurate depiction of the configuration of the test component at the elevation scanned. By running multiple CT scans at adjacent elevations, the component can be completely characterized and defects detected throughout the component. Both composite and metallic components can be inspected, with flaw detection capability on the order of 1-2 mm flaw diameter with 0.2% contrast sensitivity (0.2% density change).

The Center's CT system is one of the few systems in the United States that was constructed with variable source and detector spacing settings. This allows for optimized inspection of a wide variety of component sizes, from a minimum diameter of one inch to a maximum diameter of 50" with maximum height of 60" and maximum weight of 3700 pounds. The Center also uses software that can combine adjacent



CT slices into a three-dimensional data model of the inspected component, which can then be viewed from angles other than the original data collection angle. This can improve understanding of the location, geometry, and possible effects of detected defects. The Space Station, Space Shuttle, SRB, RSRM, External Tank, RLV, Technology Transfer, ASTP, SLI, and others are programs that this facility supports.

The CT system is located in Building 4707. The gantry is approximately 15' high by 15' wide by 20' long.

Point-of-Contact:

Ron Beshears / ED32
(256) 544-2550
ron.beshears@msfc.nasa.gov

Thermography Facility

Purpose:

To detect defects beneath insulation, paint, and laminated composites.

The space flight industry is rapidly changing and introducing stronger, stiffer, and lighter composites into vehicle designs. As a result, MSFC's inspection teams needed a more flexible and portable system for detecting defects beneath insulation, paint, and laminated composites. Thermography is a nondestructive inspection technique that uses an infrared (IR) camera to measure temperature variations and hence identity voids, foreign inclusions, wrinkled plies, separated unbonds, and low resin content in composites. In using this technique a material is thermally excited by a high-energy source (e.g., quartz lamp, or high intensity flash). As the material cools, the emitted infrared radiation can be analyzed with a thermal-imaging camera measuring the surface temperature. Different materials absorb and release energy at different rates as heat propagates through, thereby creating a thermal image related to the material quality in deeper layers of the material.

Thermography is particularly useful for examining composite materials because many are nearly invisible to x-rays. Delamination (or voids) inside the composite will create air-filled pockets that act as insulators. The area inside and around this insulated area will cool at a different rate than the remainder of the material, thus creating a slightly altered thermal image.

This facility has IR cameras capable of resolving temperature differences down to 0.025 degrees C and collecting images in a digital video format; automating and synchronizing a predictable heating source with data acquisition; and easily storing and enhancing the resulting images. The system can also quantify the size and severity of delamination. With this process, MSFC can analyze composite materials for potential delamination problems and quantify delamination/porosity within composite material. Current projects using this technique include the ET Composite Nose Cone and the composite fuel and oxidizer tank development.

Point -of-Contact:

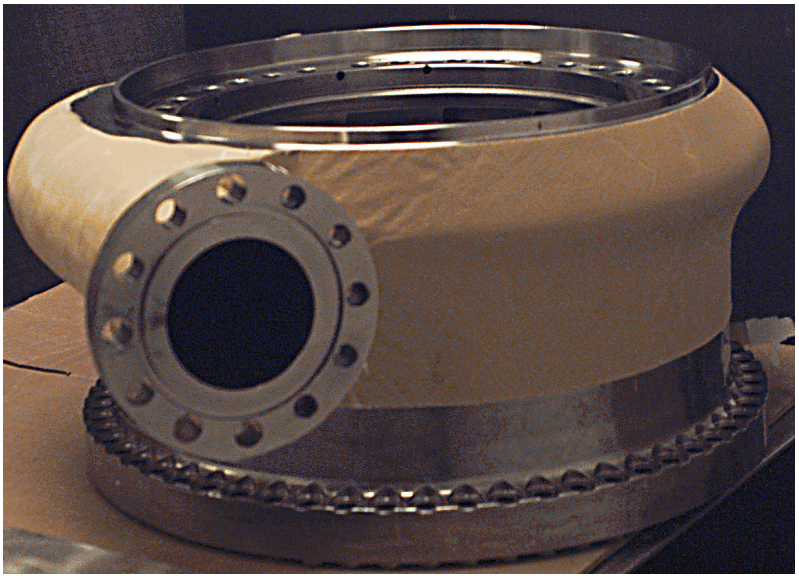
Sam Russell / ED32
(256) 544-4411
sam.russell@msfc.nasa.gov

Shearography Facility

Purpose:

To detect defects beneath insulation, paint, and laminated composites in the space flight industry.

Shearography (Shearing Holography) is an inspection technique that uses heat, vacuum or another form of agitation to identify inconsistencies in a part. The shearography camera detects minute changes of shape of a part due to heating, vacuum, or vibration. This technique can be used to find debonds in coatings, insulation, or laminated materials. This technique has been used on the Alternate High Pressure Fuel Turbopump (insulation inspection) and Pegasus Fairings.



In an electronic shearography system, a laser is passed through a beam expander which changes the laser beam into a cone of light that strikes the test specimen. The laser speckle pattern is then imaged through a telephoto lens and gathered in a Michelson interferometer to provide information on the changing shape of the specimen. The system records two images: (1) the reference image and (2) the sheared image. These images will interfere with one another, resulting in a recorded image of a laser speckle pattern indicative of the test specimen's surface slope. The system can also detect surface imperfections by recording the slope of the surface. If a defect exists below the surface, it will eventually distort the surface profile due to heating, vacuum, or vibration and be recorded by the shearography camera.

Electronic shearography has proven to be an effective means of inspecting a variety of materials for defects in multiple environments. Since implementing this system, MSFC's engineering staff can quickly adapt and integrate new inspection technologies. The system provides greater sensitivity, repeatable and uniform testing, and the ability to detect defects near inner surfaces of a closed-body structure such as fuel tanks. MSFC also uses electronic shearography to ensure product conformance and flight safety. This facility is located in Building 4711.

Point-of-Contact:

Sam Russell / ED32
(256) 544-4411
sam.russell@msfc.nasa.gov

NON-DESTRUCTIVE EVALUATION FACILITY

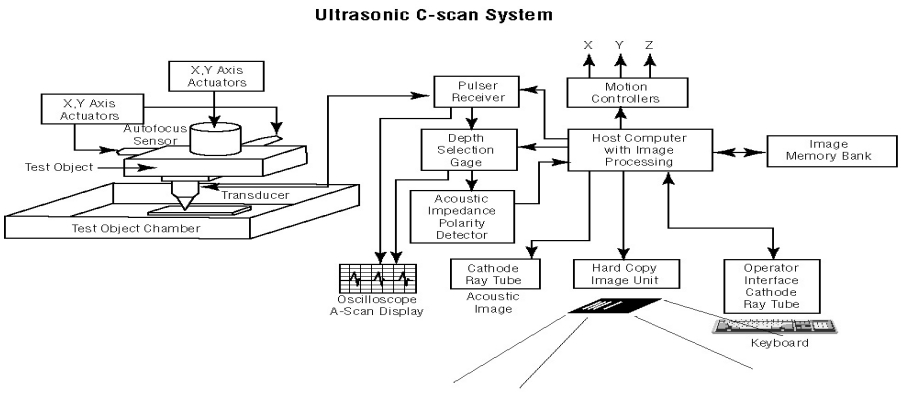
Purpose:

To nondestructively inspect and evaluate the interior of test and flight hardware for Space Shuttle and other NASA propulsion programs.

Ultrasonics

Ultrasonic nondestructive testing is the use of ultrasonics to examine or test materials without destroying the material. Ultrasonic testing involves the conversions of electrical energy into useful high frequency (commonly from 0.5 MHZ to 25 MHz) mechanical waves which propogate and interact with internal features of the material under test. An ultrasonic test may be used to measure the thickness of a material or to examine the internal structure of a material for possible discontinuances such as voids and/or cracks. Ultrasonics at the Marshall Space Flight Center consists of immersion and contact methodologies. The immersion methods are typically implemented with automated equipment while the contact methods are usually manual and hand-held.

MSFC immersion ulltrasonics consist of an immersion tank with 10 degrees of freedom with capability to inspect complex shaped hardware such as combustion chambers, rotors, nozzles, etc., with inspection envelopes 3 feet x 5 feet x 3 feet. The broadband frequency capability ranges from 150 KHz to 50 MHz. C-Scan capability along with Time-of-flight data is available.

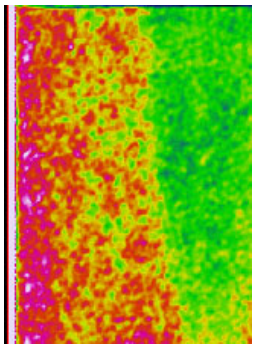


Phased array technology can be used as a bubbler or contact method. It has the capability to scan flat panels up to 24" x 24" with 5 MHz and 10 MHz and at least 32 element transducers. The resolution of these scans and the versatility (electronic scanning with multiple angles) makes this method far superior to conventional ultrasound. Information is typically shown in A-scan, B-Scan, C-Scan and sectorial views.

Useful in the area of composite inspection and characterization are ultrasonic spectroscopy and resonance bond testers. MSFC has several of these types of units which can interrogate materials with mechanical and ultrasonic resonance. This is typically done with very versatile swept frequency pulsers.

Non-Destructive Evaluation Facility

Useful in the area of composite inspection and characterization are ultrasonic spectroscopy and resonance bond testers. MSFC has several of these types of units which can interrogate materials with mechanical and ultrasonic resonance. This is typically done with very versatile swept frequency pulsers.



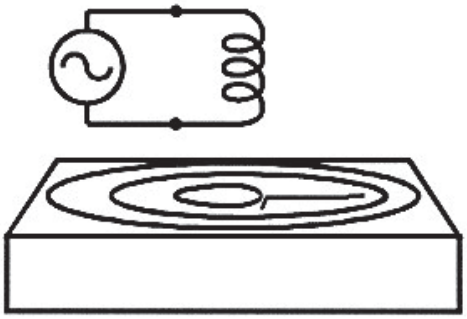
There are several non-contact ultrasonic methods in industry: laser, air, electromagnetic, etc. At MSFC, electromagnetic generation and detection of ultrasound via EMATs is available around 2 MHz. This is a purely non-contact approach and is currently hand-held.

Point-of-Contact:

Mike Suits / ED32
(256) 544-8336
mike.suits@msfc.nasa.gov

EDDY Current Capabilities

The aerospace industry, in an effort to conserve fuel and increase payload limits, is perpetually inventing new alloys and structures that are lighter in weight yet strong enough to bear the loads of launch and mission life. This often results in components that have little tolerance for even the smallest of surface flaws. The eddy current techniques being developed at MSFC can be a useful tool in identifying such flaws.



Eddy current is a nondestructive testing technique that uses magnetic fields to induce circular or "eddy" currents on the surface of conductive parts. A coil of wire at the end of a probe is energized with AC currents and held in close proximity to the material's surface by either mechanical or manual means. The difference in resistance to current flow between the coil and the eddy current generated on the part's surface is displayed in one of several modes on the screen of the test instrument. A crack or surface discontinuity on the part represents an increased resistance to current flow. Also, the higher the conductivity of a material, the shallower the eddy current depth of penetration below the surface of the material. For this reason, eddy current is considered primarily to be a surface and near-surface inspection technique. The only limitation to this technique is that it cannot be used on magnetic materials.

The eddy current equipment available at MSFC is adaptable to almost any inspection situation, whether in the lab or in the field. A total of five benchtop units, along with their accompanying array of probes and surface adapters, may be used to test for surface defects, make conductivity measurements in support of alloy verification and sorting, measure the thickness of non-conductive coatings such as paint and primer over metallic bases, and inspect both bolts and bolt holes. Probe adaptors allow a variety of surface contours to be tested also. While most work is done in the laboratory, all of the equipment may be carried into the field as well.

Projects currently employing this technique include Reusable Solid Rocket Motor (RSRM), Super Light Weight Tank (SLWT), Space Station, and many in-house developmental programs such as Friction Stir Welding. All of the equipment is located in Building 4702.

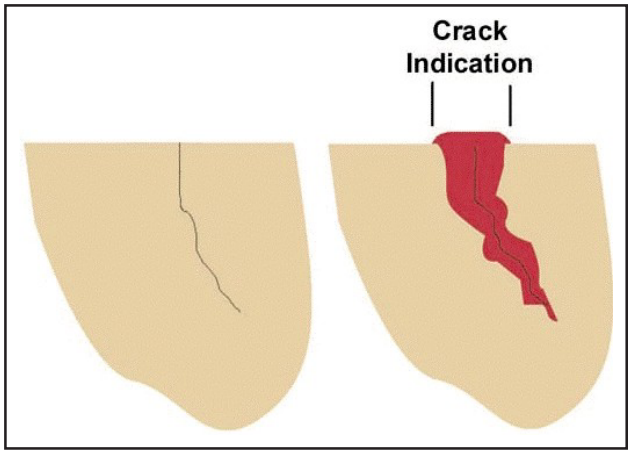
Point-of-Contact:

Craig Bryson / ED32
(256) 544-2553
craig.bryson@msfc.nasa.gov

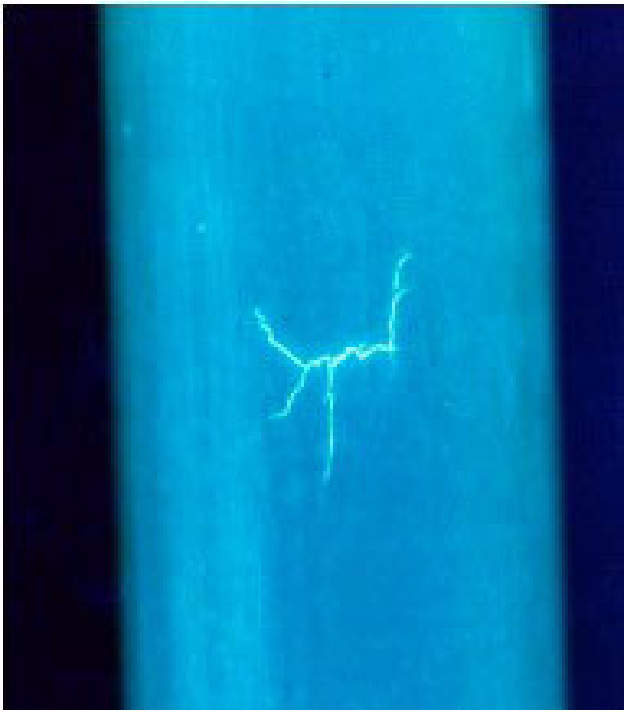
Liquid Penetrant Inspection

Penetrant inspection is a nondestructive test for defects open to the surface in parts made of non-porous material. It is used with equal success on such metals as aluminum, magnesium, brass, copper, cast iron, stainless steel, and titanium. It may also be used on ceramics, plastics, molded rubber, and glass. The technique is based on the ability of a liquid to be drawn into a surface-breaking flaw by capillary action.

Penetrant inspection will detect such defects as surface cracks or porosity. These defects may be caused by fatigue cracks, shrinkage cracks, shrinkage porosity, cold shuts, grinding and heat treat cracks, seams, forging laps, and bursts. Penetrant inspection will also indicate a lack of bond between joined materials.



Penetrant inspection depends upon a penetrating liquid entering the surface opening and remaining in that opening, making it clearly visible to the operator. It calls for visual examination of the part after it has been processed, but the visibility of the defect is increased so that it can be detected. Visibility of the penetrating material is increased by the addition of visible or fluorescent dye.



Liquid penetrant inspection is a widely used inspection technique at MSFC. Current projects using this technique include Solid Rocket Booster (SRB), External Tank (ET), Space Shuttle Main Engine (SSME), Space Station, and others.

POINT-OF-CONTACT:

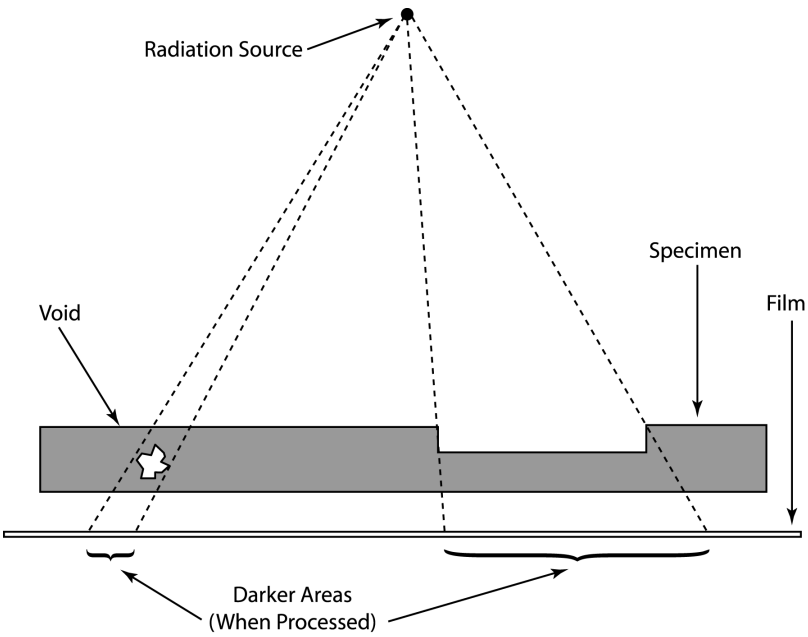
David Brown / ED32
(256) 544-7622
dave.brown@msfc.nasa.gov

Non-Destructive Evaluation Facility

Radiography

Radiography is a nondestructive inspection technique that uses x-rays (penetrating radiation) to detect internal and gross structural flaws in various materials and components. X-rays are a form of electromagnetic radiation with wavelengths from 10^{-13} m to 10^{-9} m in the electromagnetic spectrum. The x-rays are produced inside of an x-ray tube consisting of a cathode and an anode. A voltage applied across the cathode results in the acceleration of the electrons toward the anode. When the electrons abruptly strike the anode, the deceleration of the electrons results in the production of x-rays. The x-rays are either transmitted or attenuated by the object under inspection to image any flaws. Radiography is used to inspect castings, welds, brazed joints, electronic assemblies space components and aircraft. It is typically used for the detection of cracks, porosity, voids and inclusions.

The x-ray facility in Building 4702 has a RADView x-ray film digitizer with a 5 mega pixel display monitor. The digitizer runs on a Windows NT operating system. This system can be utilized to digitize exposed x-ray film, which can be saved and incorporated into reports.



MSFC has two x-ray facilities located in buildings 4702 and 4711. Both facilities have a Comet Philips x-ray system and a Kodak Automatic Film Processor. The maximum potentials/amperages on the x-ray systems in building 4711 and 4702 are 220 kV//15mA and 320 kV/15 mA respectively. The x-ray facility in Building 4702 also houses a Sperry portable x-ray system and a Lorad panoramic x-ray system. The maximum potentials/amperages for the portable and panoramic x-ray systems are 160 kV/4 mA and 200 kV/10 mArespectively. These x-ray systems offer the capability to inspect aluminum, stainless steel, titanium and composite materials. These x-ray systems are capable of inspecting up to 3.0 inches of aluminum and up to 1.5 inches of stainless steel.

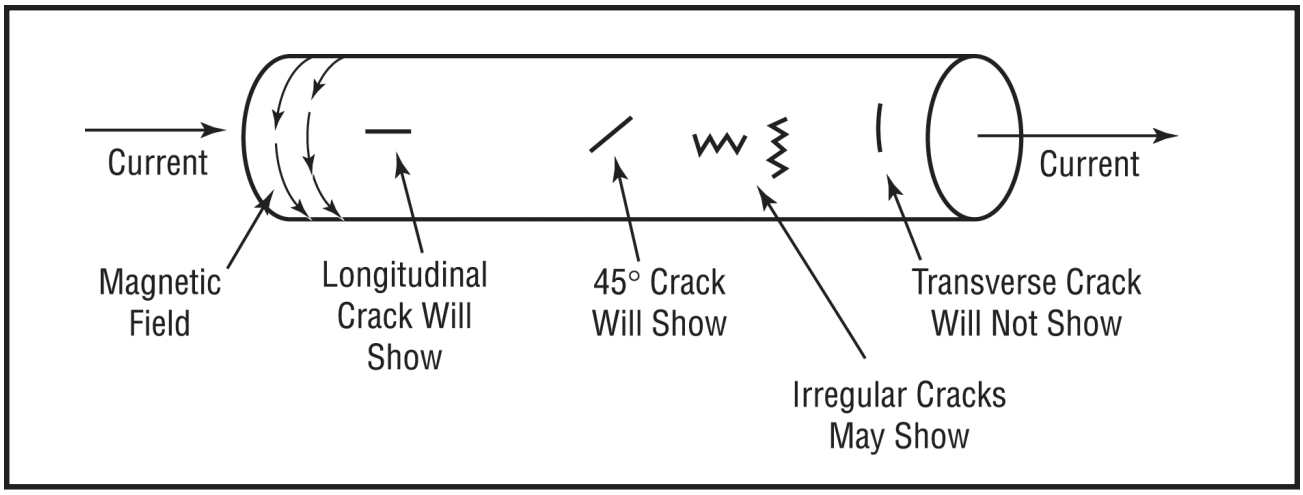
MSFC is currently augmenting its capabilities with a High Resolution Digital Radiography System. This x-ray system will utilize a charged couple device camera as the detector instead of x-ray film. The system will be able to acquire digital images after an x-ray exposure. MSFC is also procuring another filmless radiography system, which will utilize a phosphor plate instead of x-ray film. A laser scanner will be used to produce a digital image from the phosphor plate after it is exposed.

Point-of-Contact:

Linda Clark / ED32
(256) 544-9323
linda.s.clark@msfc.nasa.gov

Magnetic Particle Facility

In addition to the aerospace industry, many manufacturing facilities have employed magnetic particle testing as a quick means for interrogating the surface condition of magnetic materials and parts. For this reason, MSFC maintains the capability of performing this nondestructive inspection technique both in-house and in the field.



Magnetic particle testing makes use of the inherent conductive properties of iron-laden materials to produce indications of surface and near-surface flaws.

Current is passed through the part under test either by connecting terminals to each end of the part (direct method) or by passing the part through an energized coil of wire to induce current into the part (indirect method). The direct method produces a circular field, yielding longitudinal cracks, while the indirect method produces a longitudinal field, resulting in transverse or circumferential crack detection. To visibly enhance crack identification, either a dry powder of magnetic particles in a fluorescent liquid suspension are applied just prior to induction of the magnetic field. Optimum contrast between surface appearance and crack indication is desired and affects the decision between dry versus wet particle application. Also, the fluorescent suspension tends to be more sensitive to tighter and shorter surface discontinuities.

At MSFC a bench-type facility is maintained for testing parts approximately four feet in length and shorter. Portable magnetic yokes are also available for testing larger parts in sections and for application of the technique in the field. A demagnetizing unit is available for reducing the effects of residual fields left in the parts after testing.

Projects currently employing this technique include Reusable Solid Rocket Motor (RSRM) and several in-house experiments. This equipment is located in Building 4702.

POINT-OF-CONTACT:

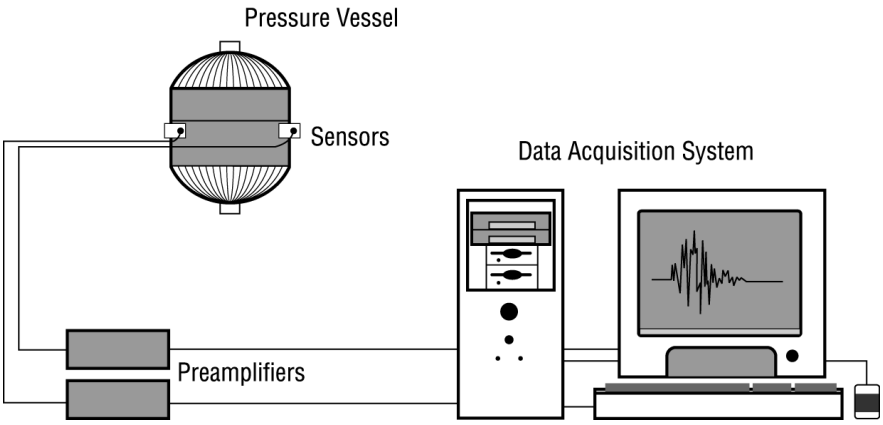
Craig Bryson / ED32
(256) 544-2553
craig.bryson@msfc.nasa.gov

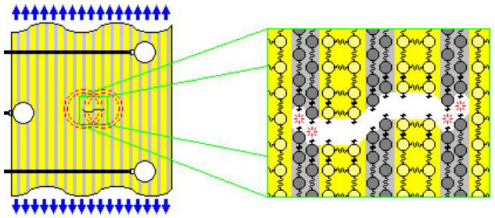
Acoustic Emission Facility

Purpose:

To better monitor the performance and quality of critical, low margin, structures by researching the applications of acoustic emmision (AE) nondestructive testing for advanced composite structures.

Acoustic emission nondestructive testing evaluates the ultrasonic sounds emitted by a structure as it is loaded. For most composite materials these sounds begin early in the loading cycle as a result of microdamage propagation from such failure modes as fiber/filament breakage, resin microcracking and delamination. The amount and severity of these modes early on in loading have been shown to be directly related to the overall quality of the composite and ultimately its failure loading condition. By monitoring these initial acoustic emissions, or lack of such, the quality of the structure can be obtained. Where all other nondestructive evaluation methods can only give the geometry of a suspected defect, AE measures active damage propagation, or in other words, defects that are truly detrimental to the performance of the structure.





The acoustic emission facility at MSFC has the capability with its four independent acoustic emission systems to monitor over sixty channels of acoustic activity. Both waveform and parametric AE data can be collected and analyzed with the systems. Advanced post processing software is available for linear, planar and 3-dimensional source location, soft computing (genetic algorithms and artificial neural networks) and statistical based data classification/sorting. Sensors are available for testing both metals and composites from cryogenic temperatures (-400 °F) to pyro temperatures (1000 °F). The facility also has a small load frame capable of applying quasi-static loads up to 30,000 pounds for stimulation of AE signals from material coupons for signal characterization.

Projects at MSFC using this technique worked at MSFC include the DC-XA liquid hydrogen tank, Spacelab Transfer Tunnel Extension, X-33 liquid hydrogen tank, Bantam RP-1 tank as well as many subscale pressure vessels. This faciltiy is located in Building 4711.

Point-of-Contact:

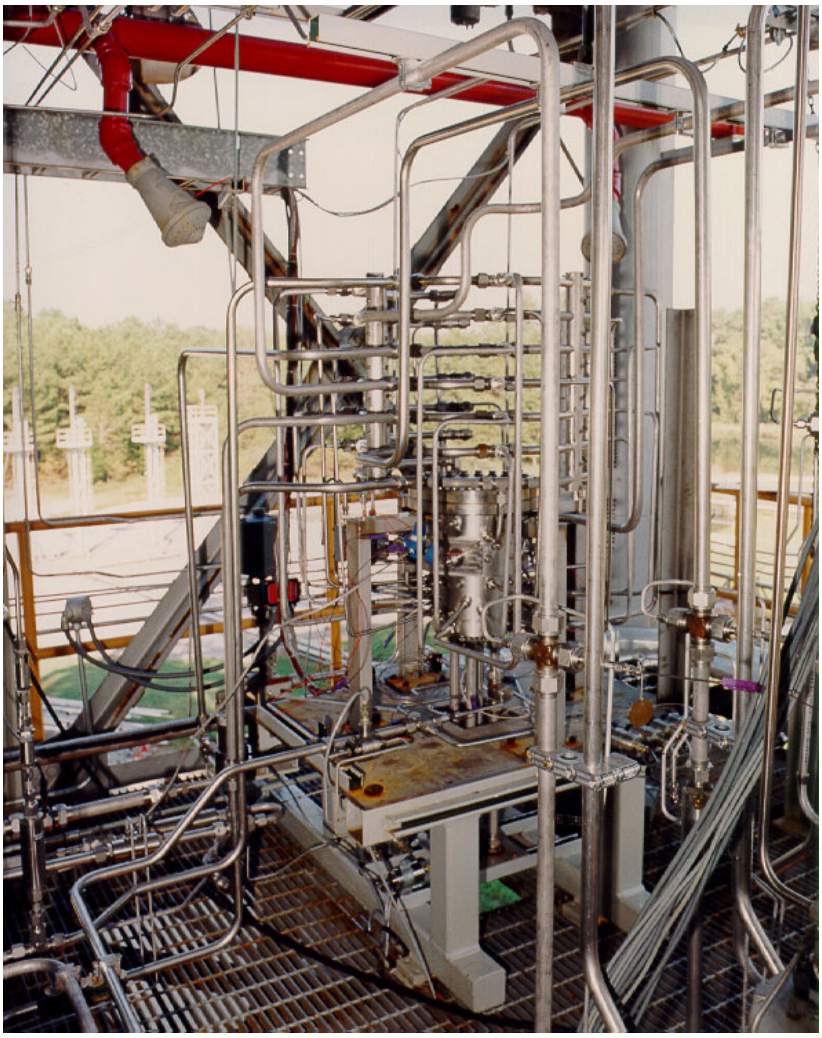
James Walker / ED32
(256) 961-1784
james.l.walker@msfc.nasa.gov

Bearing Test Facility

Purpose:

To test and validate the performance of bearings used in Space Shuttle Main Engine Program.

Bearings are a major component of high speed, cryogenic, main engine turbopumps. The bearings need to be designed to carry the loads and speeds during launch without wear or degradation. The LH2 Bearing Test Program utilizes a cryogenic test rig running in liquid hydrogen or nitrogen that duplicates as closely as possible, the operating conditions in a Space Shuttle main engine turbopump. Flight type bearings are installed in the rig, and then the shaft is rotated at speeds up to 40,000 RPM. The test rig is capable of 2000-psi internal pressures and has instrumentation to monitor pressure, temperature, speed, and loads. Test duration is typically 1000 to 1200 seconds per run. When using liquid hydrogen, inlet temperatures are -400 degrees Fahrenheit. This tester has been used to validate the use of hybrid bearings with silicon nitride balls in steel races for the Main Engine program. Hardware is also available to modify the test rig to run all hydrostatic bearings.



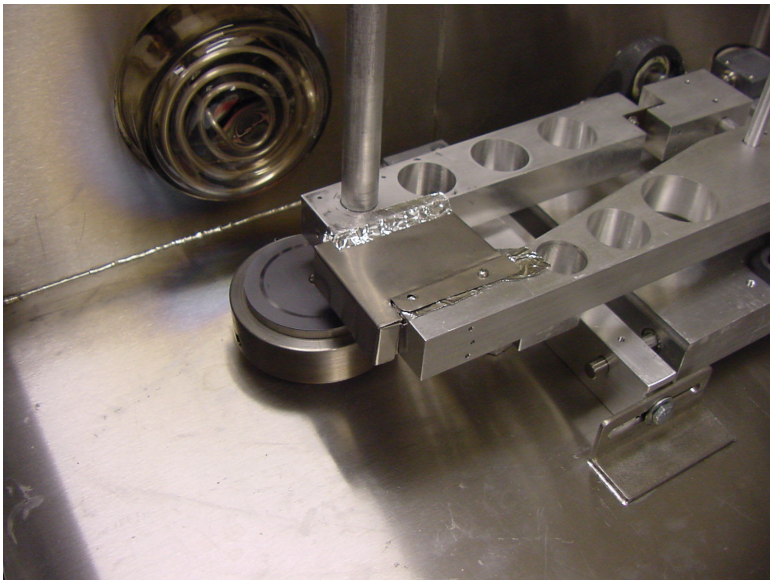
Point-of-Contact:

Robert Thom / ED32
(256) 544-2517
robert.thom@msfc.nasa.gov

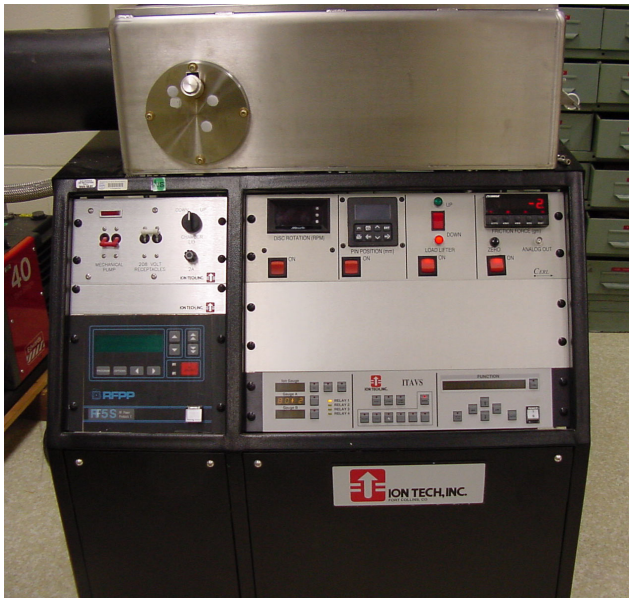
Plasma Environment Tribotester Facility

Purpose:

To test the performance of aerospace lubricants under conditions approximating the space environment.



The environment encountered in space is different from that on the earth. In space, there are concerns about ultraviolet radiation, atomic oxygen, and vacuum exposure on lubricants. These lubricants can be greases, oils, composite materials, or low friction coatings. The Plasma Environment Tribotester (PET) is a device that can closely duplicate the conditions of space while evaluating the frictional properties of lubricants. The PET uses an American Society for Testing Materials (ASTM) pin on disc apparatus that can be loaded and the speed varied while the lubricant is exposed to the conditions separately or in combination. The coefficient of friction can be determined and a relative ranking of lubricants given. This will allow designers to choose the best candidate for long life lubrication in mechanisms used in space.



Point-of-Contact:

Robert Thom / ED32
(256) 544-2517
robert.thom@msfc.nasa.gov

Pressure Infiltration Casting Laboratory

Purpose:

To advance metal matrix composite (MMC) technology through in-house alloy development and manufacturing demonstration of MMC hardware.

The pressure infiltration casting facility is for the advancement of MMC technology. MMCs are materials of interest because of their advantages over conventional materials, including high specific strength and stiffness, compatibility with hydrogen and oxygen, low thermal expansion, higher electrical and thermal conductivity than polymer matrix composites and affordability due to the manufacturing of complex parts by low cost casting process.

Metal matrix composites are reinforced metals. The reinforcements are generally ceramics in forms of fibers, particulates, fabric, wires and whiskers. Common metallic alloys include magnesium, aluminum, copper, titanium, iron, nickel and others.

Currently, at MSFC there are several efforts that are exploring the applicability of new MMC materials. These efforts include propulsion engine hardware structural jackets for combustion chambers, injector bodies, valves, flanges, turbopump housings, ducts and lines. There are several other commercial and DoD applications in service.

The MSFC pressure infiltration casting process involves these steps for particulate MMCs:

- Start with a CAD file to 3 dimensionally print a ceramic preform layer by layer
- Dry and sinter the preform to give it strength
- Machine the mold
- Fit the preform in the mold
- Heat the mold, including the alloy charge in the pressure chamber/furnace
- Apply gas pressure to infiltrate the ceramic preform with metal to obtain the MMC.

For fiber reinforced MMCs the process will differ at the preform manufacturing stage. The pressure infiltration casting still remains the same.

The casting chamber at MSFC is 7” diameter and 36” long. Although the chamber has been primarily designed to make aluminum MMCs, it is possible to use it for copper MMCs also. The general pressures used for pressure infiltration are 900-1200 psi.

Point-of-Contact:

Sandeep Shah / ED33
(256) 544-0836
sandeep.shah@msfc.nasa.gov

Thermo-Mechanical Processing Facility

Purpose:

To develop heat treatment and thermo-mechanical processing procedures for advanced aerospace materials to improve properties.

Thermo-mechanical treatments have the potential to improve material properties significantly. Advanced materials development requires optimization of both heat treatment and mechanical processing. The thermomechanical facilities are capable of performing nearly all standard heat treat procedures, which include artificial aging, annealing, austenitizing, densification (sintering), hardening, normalizing, quenching, stress relief annealing and tempering under atmospheric and vacuum conditions. Mechanical processing procedures involve both hot and cold rolling, hot and cold isostatic pressing, and isothermal and drop forging.

Hot Isostatic Press (HIP):

- Pressures up to 30,000 psi
- Molybdenum furnace heating to temperatures up to 2500ºF
- Maximum size of part – 13”diameter by 30” tall

Isothermal Forging Press:

- Accommodates sizes up to 11” diameter
- Temperatures up to 2300ºF
- Variable strain rates

Heat Treat Furnaces:

- Several furnaces that provide vacuum and ambient pressure (convective, high temperature air)
- Rated up to 3000 ºF
- Fluidized bed for rapid heating and cooling

Support Equipment:

- Fenn 2-high rolling mill
- United forging hammer

Point-of-Contact:

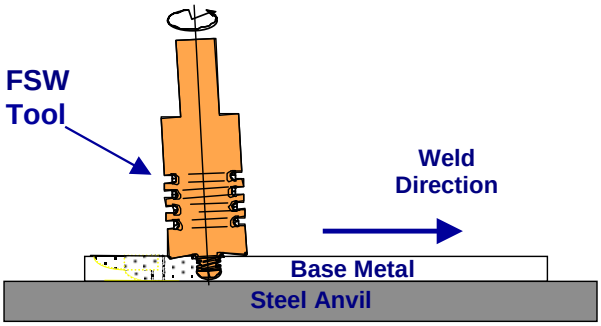
Billyar Bhatt / ED33
(256) 544-2596
biliyar.bhat@msfc.nasa.gov

Friction Stir Welding Facility

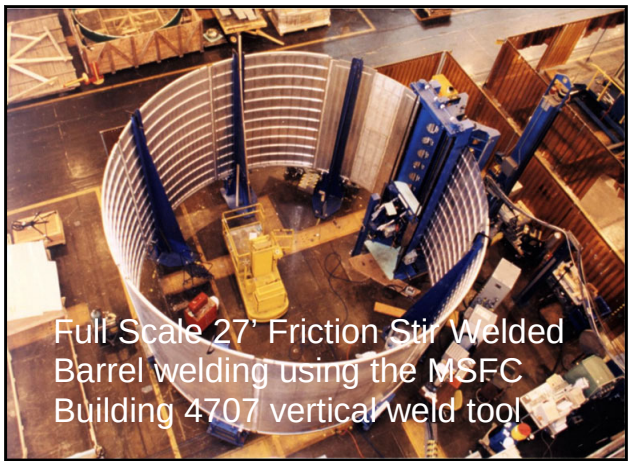
Purpose:

To investigate the friction stir welding process superior mechanical properties and lower cost for application to space vehicles.

Friction stir welding is a solid state weld process which uses a rotating pin tool to join two pieces of metal. The pin tool rotates against the work piece and generates the frictional heat required to bring the metal into a plastic state (approximately 400 degrees Fahrenheit below melting in aluminum alloys). The material is “stirred” into a homogenous and defect free weld.



NASA has demonstrated joining a wide range of aluminum and copper alloys in the Friction Sitr Welding Facility at MSFC, and has developed the process for the Space Shuttle External Tank.


Full Scale 27’ Friction Stir Welded Barrel welding using the MSFC Building 4707 vertical weld tool

Point-of-Contact:

Kirby Lawless / ED33
256-544-2821
kirby.lawless@msfc.nasa.gov

Three systems in this facility are used to investigate critical elements of the process for different applications. A research system can wled small test panels up to 0,375” thick in aluminum, with joints up to 18”{ in length, using specially designed instrumentation to measure process parameters.

The vertical weld tool can make linear welds up to 15 feet in length on parts up to 1.00” thick in aluminum. It can be used to assemble tank barrel sections from 7 ft. to 33 ft. in diameter. Joints that change in thickness along their length can be welded using the Retractable Pin Tool, invented at MSFC.

14’ Aluminum Lithium Friction Stir Welded Tank using the building 4707 Circumferential Weld Tool

The Circumferential Weld Tool has been used to weld a prototype 14 ft. diameter aluminum tank, and could be adapted for tanks from 8 ft. to 20 ft. in diameter. It welds flat test panels up to 30” in length, and has retractable pin tool capabilities. The system can be outfitted with a conventional anvil to react the forces associated with the process, or can be configured in the new “self-reacting” mode, where tooling associated with the anvil is not required.

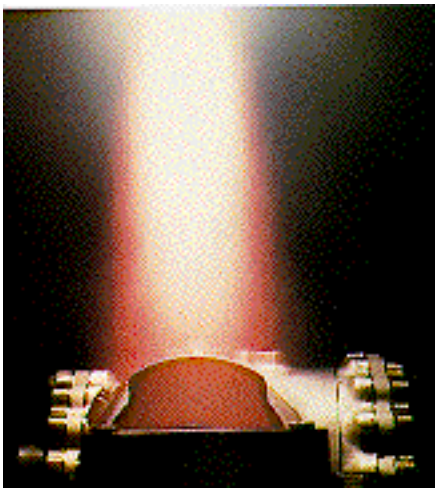
Vacuum Plasma Spray Cell Facility

Purpose:

To improve the application of protective coatings and unique metallic materials.

Improved protective coatings and unique metallic materials are under development in the Vacuum Plasma Spray (VPS) Cell. The VPS process takes place in a chamber containing a low pressure, inert gas and produces a high-quality metallurgical bond between materials. Once in the chamber, the hardware is prepared by a process known as "reverse transfer arc" cleaning, where a low-power arc scans the surface to remove any oxides or contaminants. Metallic or ceramic powder mixtures are then introduced into a high-powered plasma, where they are melted and fused to the part.

With this process, high-strength materials can be coated with other materials designed to reduce the effect of thermal shock, wear, or corrosion. Parts can also be formed by spraying successive layers of materials, with each layer specially selected for its unique properties.



Thermal spray coating and forming is a process where a coating thickness of 0.0001 to over 0.750 inch is applied to a surface. In addition, this process can layer dissimilar coating materials so that their desired properties work together, such as in functional gradient coatings. The advantage of plasma spray forming is the ability to utilize combinations of materials, such as tungsten and alumina, that are difficult to form using conventional techniques. Thermal spray coating and forming is applicable to many metallic and non-metallic substrates. The process may also be a suitable alternative to electro-plating and organic paints, especially if portability, high desposition rate, or environmental issues are important. This facility is located in Building 4707.

Point-of-Contact:

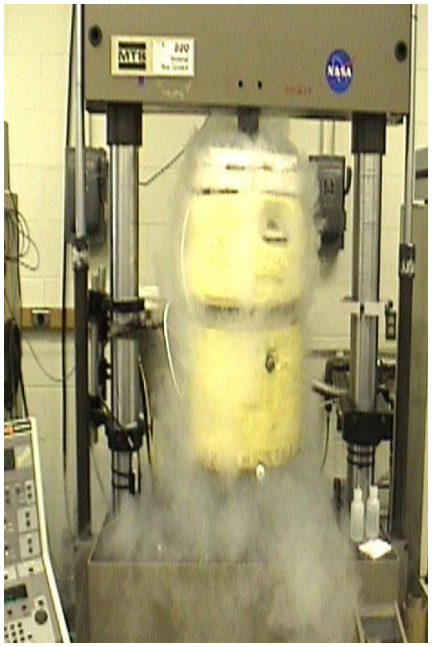
Frank Zimmerman / ED33
(256) 544-4958
frank.zimmerman@msfc.nasa.gov

Mechanical Metallurgy Testing Facility

Purpose:

To provide mechanical property data and mechanical testing services to customers, payloads, projects and Shuttle elements in support of MSFC's strategic initiatives.

The Mechanical Metallurgy Test Facility (MTF) provides mechanical property data to customers and performs mechanical testing in support of Center payloads, projects, and Shuttle requirements. The test facility is used to investigate materials used by NASA, including design data development and evaluation of process effects. It can support any standard axial tension-compression type test specified by industry and Government standards. Mechanical testing is conducted in air from -423 to 2,000 °F, in liquid helium to –423°F, in liquid nitrogen at -320 °F, and in aqueous salt baths at ambient temperature. The facility operates nine mechanical test systems (with 5-5, 5.5-, 20-, 50-, 60-, and 200-kip capabilities.) Test capabilities include tension, compression, modulus (Young's, tangent, chord, and shear), stress rupture, bending and ductility of metals and welds, three- and four-point bend, plane-strain fracture toughness, high/low cycle fatigue, crack growth rate (da/dN and da/dt), crack-tip opening displacement, fracture toughness (J_{IC}, K_{IC}, and K_{IEAC}), simulated service, and torque-tension testing of fasteners. Special component testing is also available to simulate service loads and environments under extreme conditions. Support equipment includes digitally controlled portable environmental chambers, a digital specimen measuring station, a plunge electro-discharge machine, hardness testers, a bench lathe, a milling machine, a drill press, a tensile specimen fabrication machine, a strain gauge application station, a liquid nitrogen delivery system, and a high pressure hydraulic pump room.



Point-of-Contact:

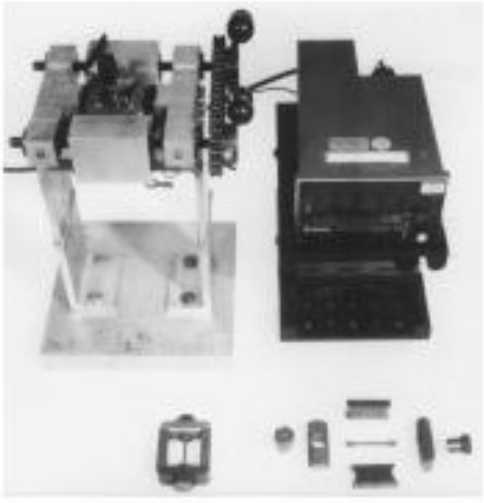
Tina Malone / ED33
(256) 544-2593
tina.malone@msfc.nasa.gov

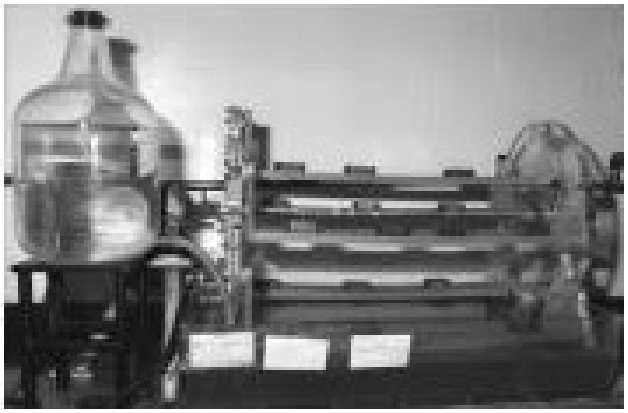
Stress Corrosion Test Facility

Purpose:

To provide stress corrosion data to our customers (payloads, projects and Shuttle elements) in support of MSFC's strategic initiatives.

Personnel in the Metallic Materials and Processes Group perform stress corrosion investigations of aerospace metallic materials and welds that are used or with potential applications in NASA programs. The results are obtained by using equipment that permits testing according to the American Society for Testing and Materials. Among the programs supported with this work are the Super Light Weight Tank, the International Space Station, the Space Shuttle Main Engine, the Redesigned Solid Rocket Motor, and the Solid Rocket Booster Programs. We strive to meet the needs of NASA programs by screening materials for stress corrosion resistance, which helps selecting better material for flight hardware and ground support equipment. These characterizations can predict the behavior of metals when subjected to sustained tensile stresses in a corrosive environment. The equipment at the Stress Corrosion Test Facility includes four corrosion testers to test in 3.5-percent sodium chloride (simulated salt water) alternate immersion in accordance with ASTM G44, two chambers that permit testing in a 5-percent salt spray per ASTM B117 and two humidity cabinets for testing in high humidity with no salt. This testing can identify materials with high, moderate, and low resistance to stress corrosion cracking in sodium chloride and high humidity environments. Materials evaluated by using these techniques include aluminum alloys, ferrous alloys, nickel alloys, and other miscellaneous metals.





Point-of-Contact:

Pablo Torres / ED33
(256) 544-2616
pablo.torres@msfc.nasa.gov

Hydrogen Test Facility

Purpose:

To provide mechanical property data and mechanical testing services to our customers (payloads, projects and Shuttle elements) in support of MSFC's strategic initiatives.

The Hydrogen Test Facility provides mechanical property data to customers and performs mechanical testing in support of Center payloads, projects, and shuttle requirements. The test facility is used to investigate materials used by NASA, including design data development and evaluation of process effects, and to evaluate and characterize materials used in conjunction with hydrogen fuels in order to determine service life. The Hydrogen Test Facility (HTF) operates custom mechanical test systems in eight structurally reinforced test cells used to simulate a range of operating environments. Cryogenic testing is conducted at atmospheric pressure in propellant-grade liquid hydrogen (-423 °F), liquid helium (-454 °F), and liquid nitrogen (-320 °F), using 20-kip, 60-kip, and 100-kip custom material test systems. Test capabilities include compression, cryogenic exposure, fatigue crack growth rate, four-point bend, high/low cycle fatigue, fracture toughness, shear, tensile, and thermal conductivity. Support equipment includes two vacuum-insulated liquid hydrogen dewars (total capacity 530 gallons) and one liquid nitrogen tank (total capacity 1,000 gallons). Gaseous testing is conducted from atmospheric to 10,000 psi in propellant-grade gaseous hydrogen, hydrogenated steam, high-purity gaseous helium, and gaseous nitrogen from –200 to 1,800 °F. Custom material test systems include 10-kip atmospheric pressure ambient temperature, two 20-kip high-pressure elevated temperature, 20-kip and 50-kip high-pressure ambient temperature. Test capabilities include compression, fatigue crack growth rate, four-point bend, fracture toughness, gaseous exposure, high/low cycle fatigue, shear, strain to crack, and tensile. Support equipment includes trailers for gaseous hydrogen (60,692 SCF at 3,750 psi) and gaseous helium (80,849 SCF at 5,000 psi), diaphragm compressors for gaseous hydrogen and gaseous helium (10,000 psi), and gaseous hydrogen purification systems (activated charcoal, molecular sieve, and alumina filter units) at 3,750 and 10,000 psi.

Point-of-Contact:

Wayne Gamwell / ED33
(256) 544-2592
wayne.gamwell@msfc.nasa.gov

Materials Diagnostic Facility

Purpose:

To provide diagnostic and failure analysis of aerospace materials.

The MSFC Materials Diagnostic Facility is responsible for analysis of aerospace structural materials through diagnostic and failure analysis methods. Failure analysis requires an understanding of applied stress, internal material behavior, and environmental influences, as well as familiarity with strengthening mechanisms, microstructures, and material design consideration of materials characterization. This facility is one of the few locations in the world where such extensive capabilities are collected in one area. These complement each other and consist of the following disciplines:

Electron Optics -- A variety of scanning and transmission electron microscopy equipment is used for high-magnification and high-resolution imaging of metallic and nonmetallic materials. The electron microscopes provide digital images at magnifications ranging from about 5x to as high as 1,000,000x. Bulk chemical analysis, from boron and higher in the periodic table, is conducted using energy dispersive X-ray analysis and wavelength dispersive X-ray analysis equipment. Equipment includes:

- Field Emission Scanning Electron Microscope
- Scanning Transmission Electron Microscope
- Environmental Scanning Electron Microscope
- Large Stage Scanning Electron Microscope
- Electron Probe Microanalyzer

Surface Analysis -- Information from the outer few atomic layers is acquired by manipulating ions and electrons within an ultrahigh vacuum environment, using the principles of solid-state physics. Our equipment provides information on all elements and can analyze to a depth of about 3 nanometers. A compositional depth profile can be obtained by sputtering away layers of material during analysis. Equipment includes:

- Scanning Auger Microscope
- Electron Spectroscopy for Chemical Analysis
- Secondary Ion Mass Spectrometer

Digital Photography -- Color and greyscale digital camers are used for image acquisition and storage.

Metallographic Laboratory -- A modern laboratory provides sample preparation and optical microscopy to characterize metallic and nonmetallic microstructures.

Failure Analysis Database -- MSFC has developed an on-line, NASA-wide failure analysis database for structural materials allowing access to information on thousands of failure analysis reports.

This facility is used to support all NASA projects other government agencies; universities; and industry.

Point-of-Contact:

Chip Jones / ED33
(256) 544-2701
chip.jones@msfc.nasa.gov

Plating Research Facility

Purpose:

To provide technical plating support, problem resolution, and alloy process development to Shuttle, International Space Station, payload projects, and to the Space Optics Manufacturing Center.

The Precision Plating Facility provides plating solutions in support of Center payloads, projects and Shuttle requirements. The Precision Plating Facility currently has capabilities for nickel, low stress nickel, “bright” nickel, and “bright” copper alloys electrolytic and electroless nickel-phosphorus plating. Future coating options include electrolytic copper and electroless nickel boron. Problem resolution in all facets of pretreatment, surface preparation, plating, and post heat treatment is accomplished with resident technical support, process analysis, and detailed procedure review. Personnel supporting the Precision Plating Facility work with scientists and engineers to provide either a standard coating for their articles or in attempting to develop a process and alloy to meet their needs. The Space Optics Manufacturing Center is supported by providing on their mandrels, a high nickel-phosphorus alloy which may be diamond turned and polished.

Point-of-Contact:

NanceJo Ogozalek / ED33
(256) 544-8933
nancejo.ogozalek@msfc.nasa.gov

Composites Fabrication Facility

Purpose:

To fabricate composite parts for space applications through the use of advanced manufacturing techniques.

The Automated Tape Wrapping Research Cell

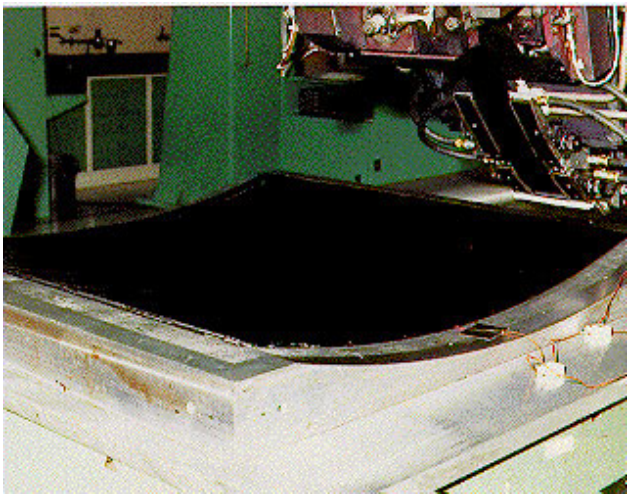
The Automated Tape Wrapping Research Cell supports the development of improved solid rocket motor nozzle manufacturing techniques. Extreme heat and pressure are applied to carbon-fiber tape and phenolic resin during the tape wrapping process to consolidate many layers into one uniform part. Nozzles and test articles are fabricated using a horizontal, computer controlled tape wrapping machine capable of producing components 2.5 m in length by 1.5 diameter. A laboratory is adjacent to the cell to determine chemical and physical properties of materials. The tape wrapping machine interfaces with a computer network that provides data collections, off-line programming and graphic simulation.

Pultrusion Equipment

The Pultrusion Equipment is controlled by a microprocessor and is capable of forming parts of any desired length and geometry. A cross section up to 30 cm square is possible. The equipment interfaces with both microcomputer and mainframe computers for data collection and analysis.

Fiber Placement Machine (FPM)

The Fiber Placement Machine provides the capability to build complex axisymmetric composites parts with concave or convex shapes. The tools used to build parts can be up to 48 feet in length and 36 inches in diameter with a maximum weight of 20,000 pounds. A method for producing part tools by mounting a cutting head on the FPM and machining the tools out of chucks of lightweight foam has been developed. Parts that have been fabricated on the FPM include: tubes, aircraft inlet-ducts, think walled tubes, human powered submarines, flat panel for testing, and Reusable Solid Rocket Motors (RSRM) nozzle overwraps.



3-D Automated Tape Layering Research Cell

The 3-D Automated Tape Layering Research Cell offers precision placement of composite tape strips to form parts, using a variety of advanced composite materials. Parts as large as 3 m wide and 10 m long can be constructed utilizing the 3.6 m gantry to lay 76 or 152 mm tape widths at speeds approaching 30 m / min. With ten axes and three sensory systems, the tape head will lay tape on a flat or contoured surfaces with far greater control and precision than manual methods. Interfaced with a mainframe computer and graphic system, tape-laying sequences can be optimized off-line before execution on the machine.

Point-of-Contact:

John Vickers / ED34
(256) 544-3581
john.vickers@msfc.nasa.gov

Sprayable Ablator Research Facility

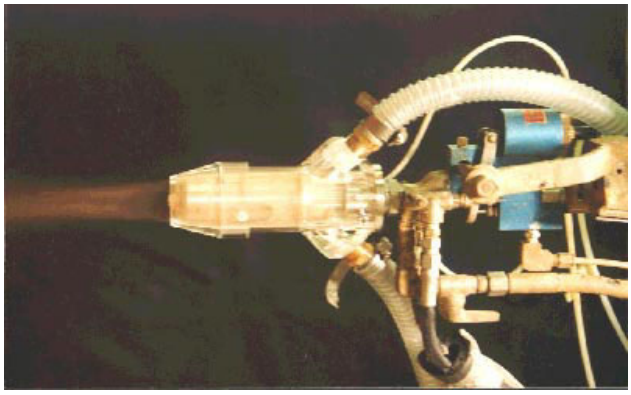
Purpose:

To be used for the development and qualification of sprayable, environmentally friendly ablative insulation to space structures.

The Sprayable Ablator Research Facility has the ability to spray target substrates in a selectable temperature and humidity-controlled environment. It is currently configured to support Convergent Spray Technology (CST), the core technology upon which the sprayable ablative insulation, MCC-1, is based. The facility is part of the National Center for Advanced Manufacturing (NCAM), located in Building 4707. It has state-of-the-art, computer-controlled processing equipment, which governs the various critical process parameters. Data acquisition equipment records the spray process parameter data for later evaluation. The facility utilizes a computer-controlled six-axis pedestal robot and turntable to enable deposition of material on the target substrate.

One of the unique features of this facility is the fact that full-scale flight hardware, up to the size of the Space Shuttle Solid Rocket Booster (SRB) forward skirt, can be accommodated in the spray booth, in addition to the more routine test panels. Access for flight hardware is gained via the removable facility ceiling and the tower's overhead crane. The capability of spraying flight hardware during the development and qualification process enabled a smooth transition to the production floor.

The Sprayable Ablator Research Facility has been instrumental in the development and qualification of a very successful ablative insulation, Marshall Convergent Coating (MCC-1). Although originally qualified for the Space Shuttle SRBs, the material was also selected for flight on the Air Force Titan IV, Boeing Sea Launch, and Boeing Delta IV.



Point-of-Contact:

Carl Lester / ED34
(256) 544-4804
carl.lester@msfc.nasa.gov

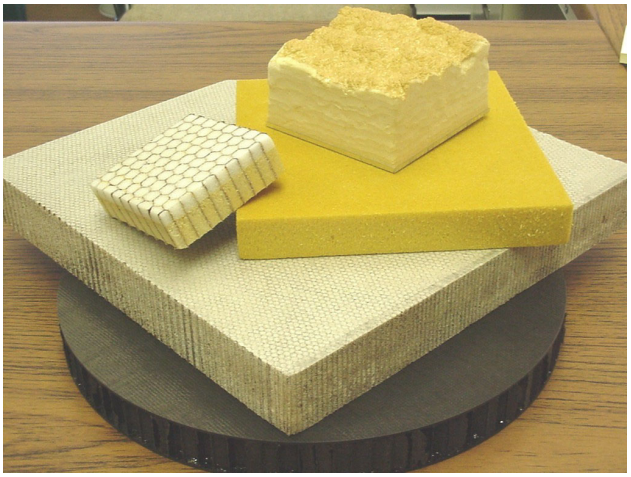
Cryoinsulation Research and Development Cell

Purpose:

To be used for the development and qualification of sprayable, pourable, and moldable environmentally friendly structures.

The Cryoinsulation R&D Cell provides MSFC with the capability of exploring and developing new insulation materials that are critical in the success of cryotankage, both current and future. The Cell has two booths, one that houses a six-axis spray robot and provides tight environmental control and one that houses hand-spray, pourable, and moldable equipment. The Cell is supplied with standard materials or uniquely MSFC-formulated materials from the adjacent Foam Formulation Facility.

The robot, in conjunction with a turntable target, stimulates the actual spraying parameters experienced during External Tank production at Michoud Assembly Facility. This allows MSFC to develop new equipment and to conduct problem resolution that is directly attributable to production hardware. The smaller spray booth is vital in the development of molded parts, closeouts, repairs, and ablator application that is necessary in the production of the external tank of the Space Shuttle Transportation System.



The Cryoinsulation Research and Development Cell has provided support for the Space Shuttle Transportation System for 20 years. The Cell was also used to successfully insulate development LH2 tanks (bondable insulation) and composite LOX tanks (manually hand-sprayed) for the X-33 Program.

Point-of-Contact:

Scotty Sparks / ED34
(256) 544-2670
scotty.sparks@msfc.nasa.gov

Nonmetallic Material Mechanical Property Characterization Facility

Purpose:

To evaluate mechanical properties of nonmetallic materials for use on NASA projects.

The mechanical properties of materials are tested at cryogenic to elevated temperatures utilizing a variety of test machines. The resulting data provides information to engineers and designers on the mechanical behavior of materials in a number of environments. The facilities are used to support the Space Shuttle, the Space Station, and many other projects.

The test lab consists of six Instron and MTS test frames ranging from 5000 to 100,000 pound capability. All of the test machines have digital data acquisition systems capable of recording various inputs such as load, strain, time, etc. State-of-the-art software is utilized in data acquisition, reduction, and analysis. Internet connections facilitate the transfer of test data.

Through the use of ovens, furnaces, and cryostats testing is performed in extreme environments. The ovens are used to maintain a test specimen at constant elevated temperature. Thus, testing is performed in environments representative of the material's service temperature.

The test lab contains many of the fixtures required for ASTM standard test methods. Mechanical testing is performed on nonmetallic materials such as: polymers, composites, adhesives, coatings, films, and fibers. The data obtained are used to develop allowables for design, qualify materials for flight, and support manufacturing processes.

Instrumentation such as strain gages, linear voltage displacement transducers, extensometers, and video extensometers are used to make high resolution strain measurement possible. Thus, moduli can be determined from the extremes of high modulus carbon fiber composites to high elongation elastomers.

The facility also has two unique capabilities: (1) a fixture developed for tensile testing composites submersed in liquid nitrogen and (2) a programmable quartz lamp heater that can follow a specific heating profile during a test. The cryogenic tensile fixture was recently used for developing allowables for the X-34 composite liquid oxygen tank and is currently in use evaluating composite materials for microcracking. This new fixture/cryostat design has significantly reduced the time required to test composites at –320°F. The high temperature facility was recently used to develop allowables for the Solid rocket Booster (SRB) composite nose cap.

Point-of-Contact:

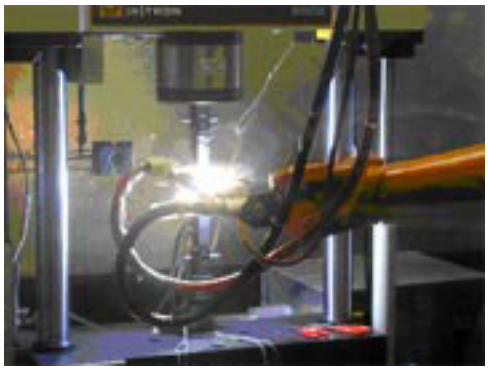
Andy Hodge / ED34
(256) 544-4952
andy.hodge@msfc.nasa.gov

Plasma Torch Test Bed Facility

Purpose:

To enable relative performance characterization of ablative materials by exposing them to conditions similar to the internal environment of a rocket motor.

Ablative materials are commonly used in rocket systems for components exposed to extremely high heat environments, such as Space Shuttle Super Light Weight Tank (SLWT) nose caps, and Reusable Solid Rocket Motor (RSRM) nozzle liners and case insulation. The Plasma Torch Test Bed (PTTB) facility provides an inexpensive rapid turnaround test that is well characterized and may be used to accurately predict material performance in service environments.

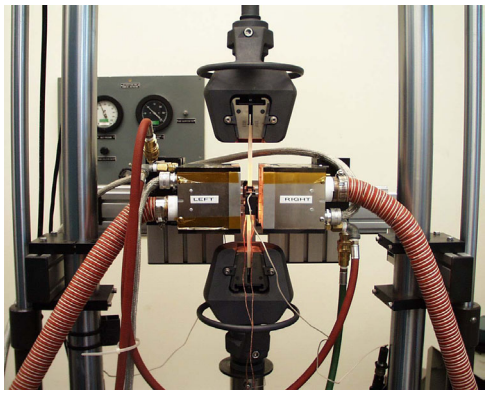


Ablative materials are sacrificially lost while expending incident thermal energy in a self-regulating heat and mass transfer process. The level of performance of an ablative material in a given environment is generally indicated by (1) the amount of material lost (or eroded), and (2) the amount of remaining material that has been thermally affected (or charred). Inside a solid rocket motor, impingement of particles from the burning propellant may induce additional mechanical erosion, thus increasing the total rates.

The PTTB employs a supersonic plasma jet to induce a very high level of heat flux on the surface of a material specimen, which results in erosion and charring. A particle feeder may be used to introduce particles into the plasma plume, resulting in high velocity impingement of molten particles on the specimen surface. Testing of different materials exposed to the same heat flux and particle impingement levels provides an indication of their relative performance and may be used for candidate screening.

Recent statistically designed experiments conducted on RSRM case insulation materials indicate that the PTTB is capable of replicating the dissimilar performance of a specific material pair exposed to the same environment, as observed in full scale testing. No other sub-scale test bed has reproduced this discrimination.

Other material phenomenon, such as pocketing (sudden ejection of material fragments from the surface due to heat induced internal pressurization) may be exhibited in the PTTB as well. Screening tests at conservative (higher than service) heat flux levels may be implemented on representative samples to assure that a lot or batch of material does not exhibit an unacceptable tendency toward such phenomenon.



Point-of-Contact:

Matt Lansing / ED 34
(256) 544-4339
matt.lansing@msfc.nasa.gov

Advanced Bonding Technology Facility

Purpose:

To develop and evaluate adhesive bonding processes for use on NASA projects.

With emphasis being placed on weight reduction in space propulsion systems, non-metallic joining processes are receiving increased use. Adhesive bonding is a widely used joining technique for buildup of structural components. The Advanced Bonding Technology facility is equipped with the basic tools to conduct adhesive bonding process development and characterization tests to support both design and manufacturing activities that support the Space Shuttle, the Space Station, and many other NASA projects.

The adhesive bonding lab consists of a clean work area with an environmental control system that maintains controlled temperature, humidity, and particulate filtration. The lab is located directly adjacent to a surface preparation and cleaning area with pass through access to the bond lab. The bonding area contains various adhesive mixers with vacuum deairation capability and control in process adhesive temperature for exothermic materials. Various configurations of test specimens are prepared to provide designers with structural properties to be used in the design of differing systems. These include both basic tensile coupons and more complex specimens used to determine shear strength capability and fracture properties of bonded systems.

The test lab contains many of the instruments to characterize adhesive processes such as viscometers and gelation timers. Once the adhesive processing, surface preparation and testing is complete, the collected data is analyzed and used to develop allowables for design, to qualify adhesive materials for flight, and to support manufacturing processes at MSFC.

In addition to performing process development work, the facility also has the capability to be used to manufacture small one of a kind prototype hardware.

Point-of-Contact:

Mike Prince / ED34
(256) 544-2678
mike.prince@msfc.nasa.gov

Rapid Prototyping Facility

Purpose:

To fabricate three-dimensional models directly from computer data.

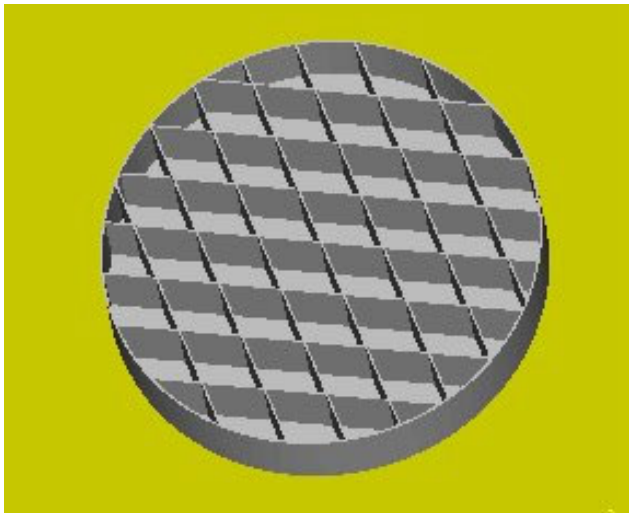
MSFC hosts a world class rapid prototyping facility in their Productivity Enhancement Complex, which encompasses every domestic rapid prototyping system currently sold commercially, as well as research systems in pre-manufacturing stages. These technologies provide a streamlined verification system for projects in the design phases, as well as checkpoints later in the game.

Rapid Prototyping (RP), in this context, refers to a collective set of manufacturing technologies that fabricate three-dimensional models directly from computer data without the need for conventional fixtures or numerical control code generation. These additive manufacturing techniques build parts in thin layers, from the bottom up, essentially "growing" apart in the selected material. RP technology significantly reduces the cost and time to develop solid models and evaluate this form, fit, and performance prior to manufacturing the finished part. Models that once usually took days or weeks to produce are now being completed in a few hours. In addition, the design engineer gets to see, hold, and examine the concept part much earlier in the design stages, thereby reducing costly rework of mating parts and assemblies due to design changes. With MSFC's unique RP capabilities, the need for mock-ups and other intermediate steps (required to produce flight quality products) are being phased out as new materials are developed and larger size parts become more feasible to produce.

MSFC not only applies RP to the design and manufacturing projects, but also works to:

- Improve existing system's materials capabilities,
- Develop/refine secondary applications, such as investment casting and soft tooling,
- Apply RP technology to manufacturing in space and on other planets.

Capabilities available in-house are: stereolitography, fused deposition modeling, laminated object manufacturing, selective laser sintering, three dimensional printing, and multijet modeling.



Point-of-Contact:

Ken Cooper / ED 34
(256) 544-8591
ken.cooper@msfc.nasa.gov

Robotic Water Blasting Facility

Purpose:

To clean surfaces with automated high-precision and high-pressure streams of water.

This facility, located in the National Center for Advanced Manufacturing (NCAM) of Building 4707, possesses the capability to direct a powerful spray with high precision and accuracy to remove contaminates and corrosion and also selectively remove coatings such as paints, adhesives, ablatives, insulations, etc. from many different substrate types having simple or complex geometries. This automated facility features two high pressure Hammelmann pumps, one capable of delivering 32 GPM of water at 20,000 psi and another capable of delivering 13 GPM of water at 36,000 psi. From a pump room these systems feed high pressure water to any one of various nozzles, including straight, angled or rotating (up to 2,000 rpm), located within an isolated blast room. The blast room houses an automated delivery system, one of two turntables (14' diameter and a 6' diameter), a waste collection system (capable of filtering hazardous waste), remote operated camera for displaying and recording, and a high volume air exchange unit. Operation can take place manually but usually takes place remotely from a sound attenuated control room.

Point-of-Contact:

Steve Burlingame / ED34
(256) 544-8860
steve.burlingame@msfc.nasa.gov

Collaborative Engineering Workcell Facility

Purpose:

To provide an engineering workcell that allows collaborative engineering and manufacturing among MSFC, industry partners, and universities.

The Collaborative Engineering Workcell provides an ideal environment for engineering design and process development, meetings, training classes, and remote teaching. The Workcell provides the following capabilities:

- high performance engineering workstations
- engineering design software tools
- process simulation software tools
- SMART Board system with overhead projector
- videoconferencing system

High Performance Engineering Workstations and Software Tools

The Collaborative Engineering Workcell is equipped with SGI and Dell machines running the Windows NT operating system. These high performance workstations provide the computational power needed for solid modeling and the development of off-line manufacturing simulations. Developing models and simulations not only give the user a visual picture of the part and the manufacturing process, but it also provides critical manufacturing data such as collision detection, near-misses, tolerance detection, and cycle run-times. Because the manufacturing process is optimized off-line, the manufacturing costs are reduced.

SMART Board with Overhead Projector

The SMART Board is an interactive whiteboard that turns a computer and a projector into a powerful tool for teaching, collaborating and presenting. With a computer image projected onto the board, users can simply press on its large, touch-sensitive surface to access and control any application stored on the associated computer. The system allows you to capture notes and highlight important information and then distribute the information among the group. The SMART Board helps save time, increase interactivity, and improve communication.

Videoconferencing System

The Polycom Videoconferencing System provides a 384 Kbps ISDN connection to anywhere in the world. This system provides the capability for remote teaching and remote presentations. The live, real-time interaction

provided by this system not only provides for real-time collaborative work, but also decreases the need for travel to other agencies and industry partners.

Point-of-Contact:

Majid Babai / ED34
(256) 544-2795
majid.babai@msfc.nasa.gov

Solid Fuel Mix/Cast Facility

Purpose:

To fabricate solid hybrid fuel and solid rocket simulants for Solid Rocket Motors (SRM) materials testing and to evaluate solid fuel ingredients.

In fulfilling its charter to provide expertise and support in nonmetallic materials for cross-cutting engineering functions, the Non-Metallic Materials and Processes has established the solid fuel mix/cast facility.

Located in Building 4767, the facility can produce from 1 pint to 10 gallons of solid fuel in a single mix. The facility is equipped with 4 vacuum mixers with heating/cooling jackets, including a high shear mixer, which can be used for the manufacture of solid fuel, liners, or inert simulant of solid rocket propellant. Processing support equipment includes a 16" diameter vacuum casting bell and a cure oven.

Developed initially to support Reusable Solid Rocket Motor (RSRM), the facility has been instrumental in providing fuel grains to various small solid rocket motor test beds and gas generators. These are used to evaluate the materials response to the hot gases and particle impingement of the solid rocket motor environment.

The facility is used not only to cast fuel grains. The facility has the capability to manufacture Propellant-Liner-Insualtion (PLI) samples for mechanical and physical property tests, and has provided PLI test specimens used in the establishment of a Joint Army, Navy, NASA, and Air Force (JANNAF) standard test method. Characterization of various solid propellant and liner ingredients and their performance within the materials systems can be assessed using this facility.

Point-of-Contact:

Louise Semmel / ED34
(256) 544-3650
louise.semmel@msfc.nasa.gov

Ceramic Composite and Ceramic Testing Laboratory

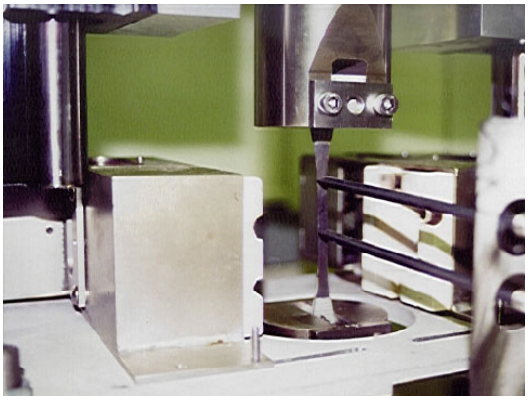
Purpose:

To provide mechanical (high frequency, creep, and low cycle fatigue, tensile, compression, 4-point bend, and interlaminar shear) characterization of ceramic composite and ceramic materials in high temperature air and cryogenic environments.

The Ceramic Composite and Ceramic Testing Laboratory (CTL) located in Building 4612 provides an environment for the material selection of advanced ceramics for 2nd and 3rd Generation space transportation applications. These ceramic composites are expected to play a major role in cost reduction and increasing safety and reliability of the Space Launch Initiative (SLI) program. This laboratory will create a very significant database for advanced ceramic composite materials. It is necessary to identify processes and to select material constituents in order to obtain durable ceramic matrix composites, which would be initially verified by testing in this laboratory. Analysis of failure mechanisms is conducted to support process development and to determine suitability for specific applications. The CTL supports several projects at MSFC: 3rd Generation Nondestructive Characterization Life Determination, 3rd Generation TBCC & ISTAR, and Various SBIR Programs.

The CTL tests fracture and fatigue of these materials in variable environments. The laboratory's capabilities include testing at room elevated temperatures. Testing facilities include:

- Slow cycle Electromechanical Tester
  Test Rate: 1 micron/hour to 350mm/min
- Fast cycle Servohydraulic Mechanical Tester
  Test Rate: 0 to 1000 Hz, with accelerometer and piezoelectric load cell
- Two Dead Weight Creep Frames with Linear Bearings to prevent parastitic strains, for ultimate strain materials
- Four Point Bend Testing Fixtures for ceramics (0° - 1400°F)
- Environmental Chamber for Mechanical Testing (-150°-315°C).



The CTL provides a unique opportunity to test ceramic materials at a much higher fatigue cycle. The specialized MTS Servohydraulic Mechanical Tester has a frequency of 0 to 1000 Hz, whereas most machines only go to 100Hz. This machine will allow the opportunity to establish high frequency trends that will better represent the vibrations endured by space transportation components.

Point-of-Contact:

Sarah Howse/ ED34
(256) 544-7418
sarah.howse@msfc.nasa.gov

Materials and Processes Technical Information System Facility

Purpose:

To record and disseminate a NASA-wide database about materials to help assure safe material selections for NASA-produced space flight hardware.

The Materials and Processes Technical Information System (MAPTIS) characterizes over 32,000 unique material codes and over 66,000 unique test codes by recording attributes of each material in an Oracle database. These attributes include information about the material's characteristics and information about how the material reacts to various tests while being exposed to specific environmental conditions. Before introducing any materials data into the MAPTIS, NASA materials engineers evaluate the data to verify that it is of the highest quality.

Material test results and material usage information are collected by the MAPTIS from various NASA centers, international aerospace partners, and contractors. The MAPTIS is regularly populated with new materials test information, while existing information is continually evaluated to maintain its quality. All materials are rated in order to simplify the selection process for aerospace designs. Currently, the MAPTIS has over 800 users, including over 108 foreign users.

The MAPTIS database is password protected. Different user access levels prohibit unauthorized use. Some applications are open to all users (such as the Material Properties, Material Test Results, and Standard / Commercial Parts), some are NASA-wide applications (such as the Material Identification Usage List, Material Usage Agreements, and Material Failure Analysis), and some are facility-specific applications (for Goddard Space Flight Center Testing Information, White Stands Test Facility Test Results information, and Marshall Space Flight Center Material Testing Results database).

The Materials Processes and Manufacturing (MPM) Department provides web sites to introduce special materials topics to the public: http://map1.msfc.nasa.gov/WWW_Root/html/page7.html hosts materials related databases, including MAPTIS links and the MAPTIS Account Request Form. It enables access to material test results and provides links to other materials web sites.

This web site -- http://map3.msfc.nasa.gov/mapwebhome.html:

- The Aerospace Materials, Processes, and Environmental Technology (AMPET) conference, and
- The NASA Materials Replacement Technology Team (NMRT2).

MAPTIS

Point-of-Contact:

Rich Wegrich / ED35
(256) 544-2626
rich.wegrich@msfc.nasa.gov

Materials Combustion Research Facility

Purpose:

To provide screening of materials for their combustibility and flammability properties and for their performance in oxygen-rich environments.

The Materials Combustion Research Facility (MCRF) tests materials, parts, and complete assemblies to determine how compatible the components are with the rigorous pressure, oxygen, thermal, and mechanical friction conditions common in the space environment. Materials that might be in contact with liquid oxygen (LOX), e.g., materials being considered for a liquid oxygen fuel tank, must be tested to determine the conditions under which they will burn or spark or otherwise threaten mission success. Materials that might be in contact with gaseous oxygen (GOX), e.g., materials for rocket injectors, or other reactive fluids, such as hydrogen peroxide, must also be tested. Astronaut safety must be assured by restricting materials that give off noxious or poisonous gases or that may promote combustion.

The Materials Combustion Research Facility is certified to perform many of the tests per NASA-STD-6001 “Flammability, Odor, Off-gassing and Compatibility Requirements & Test Procedures for Materials in Environments That Support Combustion” plus other special purpose tests. Test capabilities include:

- Testing of materials and assemblies for toxic offgassed products
- Mechanical impact testing in LOX or GOX in pressures from ambient up to 10,000 psi and temperatures up to 315 °C (600 °F)
- Flammability testing of non-metallic materials at various oxygen concentrations in pressures up to 50 psi
- Flammability testing of metallic materials and composites in GOX in pressures up to 10,000 psi.

Recently added to the MCRF are unique test systems for determining the LOX compatibility of composites and a new facility for thermal vacuum stability analysis.

Point-of-Contact:

Eddie Davis / ED36
(256) 544-2490
eddie.davis@msfc.nasa.gov

Chemistry Laboratory Facility

Purpose:

To characterize through chemical testing candidate materials to be used in spaceflight related applications and to ensure safe working environment

Wet Chemistry Analysis

Sample analysis often involves the use of wet chemistry techniques such as acid digestion of solid samples or titration methods for determining analyte concentrations within a liquid sample. Most wet chemistry procedures are performed in room 1504 of Building 4612. This room is outfitted with fume hoods, special chemical storage facilities, and a variety of glassware and other items necessary for safe wet chemistry operations. Gravimetric, precipitation and colorimetric procedures are also performed in this facility. This facility also includes an extensive array of analytical balances. The Lab also maintains spectrophotometry capabilities as well.

Mass Spectroscopy

In mass spectrometry, a substance is bombarded with an electron beam having sufficient energy to fragment the molecule. The analysis of mass spectroscopy information involves the re-assembling of fragments, working backwards to generate the original molecule. Mass spectroscopy has become one of the most important instruments used in modern analytical chemistry.

In addition to operating stand-along MS systems, the Chemistry lab operates several Gas Chromatography-Mass Spectroscopy instruments (GC-MS).

The Lab also has a CEC Model 21-620 that is configured with a below atmospheric pressure inlet system. This mass spectrometer is used to measure permanent gases.

Infrared Spectroscopy

The chemistry lab recently installed a new Nicolet FTIR system. This system is comprised of three major components, a standard bench spectrometer, a microscopic FTIR component and a Raman spectrometer. The bench

spectrometer provides multiple sampling configurations, allowing transmission, reflectance, Attenuated Total Reflectance (ATR) and Specular Reflectance techniques to be employed. This system is able to analyze a wide range of organic and inorganic materials.

Chemistry Laboratory Facility

Thermal Analysis

Capabilities in the Lab include a Differential Thermal Analyzer (DTA), a Differential Scanning Calorimeter (DSC) and a Thermogravimetric Analyzer (TGA). Sample analysis using TGA methodologies can be accomplished using either a standard furnace or a high temperature furnace capable of heating samples up to 1500 degrees Celsius.

The Chemistry Lab also provides unique analytical capabilities by integrating both thermogravimetric and infrared analysis techniques into a single instrument. By coupling these techniques, evolving gases generated during sample decomposition in the TGA is directed into an infrared spectrometer for chemical speciation. Consequently, both thermal decomposition and chemical characterization of a material may be obtained in a single sample run, providing a more definitive and comprehensive characterization of the material.

Inductively Coupled Plasma Emission Spectroscopy (ICP)

The Chemistry Lab has a Thermo Jarrell Ash ICP system. This instrument is capable of analyzing dozens of elements within a liquid sample within a matter of minutes. Additionally, this system has a laser ablation system that allows solids to be examined without the need for sample dissolution.

Inductively Coupled Plasma / Mass Spectroscopy

In addition to operating a stand-alone ICP system, the Chemistry Lab also operates an ICP coupled with a Mass Spectrometry (ICP-MS) system. ICP-MS is the fastest growing trace element technique available today. The major reason for the technique's unparalleled growth is its ability to carry out rapid multielement determinations at the ultra-trace level.

X-Ray Analysis Techniques

The Chemistry Lab often uses x-ray spectroscopy for specimen analysis and characterization. The chemistry lab maintains two x-ray fluorescence instruments, both manufactured by Spectrace Instruments. This is a non-destructive technique that is able to analyze solids and liquids and determine concentrations down to the PPM range. The Chemistry lab facility also has a Bruker D5005 diffraction system. Both powder and solid samples may be examined in this system.

Chemistry Laboratory Facility

X-Ray Analysis Techniques

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Environmental Chemistry Laboratory

The Environmental Chemistry Laboratory analyzes MSFC's water, soil, air, and hazardous waste to ensure the quality of Marshall's natural environment. The Chemistry Group has direct control over environmental areas that MSFC is required by law and regulation to report.

The laboratory's inventory includes a total organic carbon analyzer for assessment of deionized water; an ion chromatograph for determining chlorides, phosphates, nitrites, nitrates, and

fluorides in water; a Microtox test system, which uses microorganisms as test reagents and biosensors; an inductively coupled plasma/mass spectrometer for sensitive trace element analysis; a gas chromatograph/mass spectrometer to analyze VOCs and semi-VOCs and a newly installed liquid chromatography system as well.

Contamination Control Laboratory

Studies are ongoing in the effort to find suitable solvents for the replacements of Freon and Perchloroethylene. These materials have long been used in large-part and tube cleaning operations here at Marshall.

NASA Materials Replacement Technology Team (NMRT2)

This team, formerly known as the NASA Operational Environment Team (NOET), is chartered to support and facilitate those materials replacement technologies that will assist NASA in achieving environmental compliance throughout all of its many endeavors.

This team is leading NASA's review of 30 Clean Air Act National Emission Standards for Hazardous Air Pollutants (NESHAPS). The center of attention is on the contents of:

Title I: Volatile Organic Compounds (VOCs)
Title III: Hazardous Air Pollutants (HAPs)
Title IV: Ozone Depleting Chemicals (ODCs)

NMRT2 also closely follows research and development of replacement technologies, technology data exchanges, and supports the Aerospace Materials, Processes, and Environmental Technology Conference.

Point-of-Contact:

Robby Newton / ED36
(256) 544-7880
robby.newton@msfc.nasa.gov

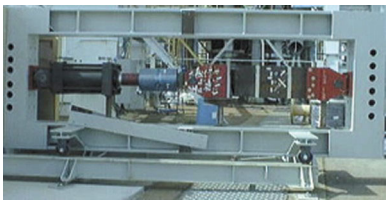
Materials Environment Test Complex

Purpose:

To test new materials for space flight applications.

The MSFC Materials Environment Test Complex (METCO) provides a one-of-a-kind test capability. The testing simulates flight profile aerothermal environments and material performance patterns in a single test environment. For anomaly investigations, screening tests, and development programs, the facility offers customers substantial schedule, test flexibility, and cost benefits over larger test facilities. The METCO also offers thermal imaging support to provide its customers with real-time thermal response and gradients of the test article. Portable systems are available for performing instrumentation and testing, as well as data acquisition and reduction, either on-site or in other locations.

METCO encompasses several test stations, including a Mach 4 combustion-driven wind tunnel (Improved Hot Gas Facility), a radiant heat lamp system, a 1-million-pound tensile test station, a thermal acoustic test station capable of delivering 170 dB (low- and high-frequency ranges), and elaborate data acquisition systems. A hyperthermal test station is under construction, and a cryogenic biaxial test capability is in design. The METCO has tested material in this state-of-the-art facility for use in America's premier space fleet – the Space Shuttle Orbiter, External Tank, Solid Rocket Boosters and Motors, as well as the Titan and Delta rockets.



Improved Hot Gas Facility (IH&F)

The IHGF is a unique, world-class GH_2/air combustion-driven wind tunnel used primarily for thermal protection system testing and aerothermal definition. During a test, combustion products are expanded from the combustion

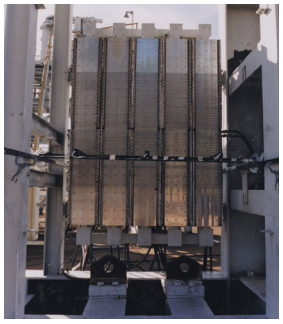
chamber through a 2-dimensional nozzle into a 16-in. x 16-in. test section. A Mach 4 flow environment is induced, and up to 30 Btu/ft^2 /sec of convective heating can be obtained. The tunnel has been upgraded to include a 300-kW radiant heat lamp system, a model insertion system with varying wedge angle, and improved tunnel control capabilities. The radiant heat lamp system supports combined heat inputs in the wind tunnel and can be used to apply radiant-only heating to test articles.

Large-Capacity Tensile Test Station

A recent addition to the METCO is the tensile test station. This test capability offers uniaxial load testing for large test articles. The station is capable of up to one-half million pounds of tension at typical metallurgical testing strain rates. These tests can be conducted at cryogenic, ambient, and elevated temperatures ranging from –450 °F to 800 °F. The test articles may be up to 2 ft wide and 4 ft long.

Materials Environment Test Complex

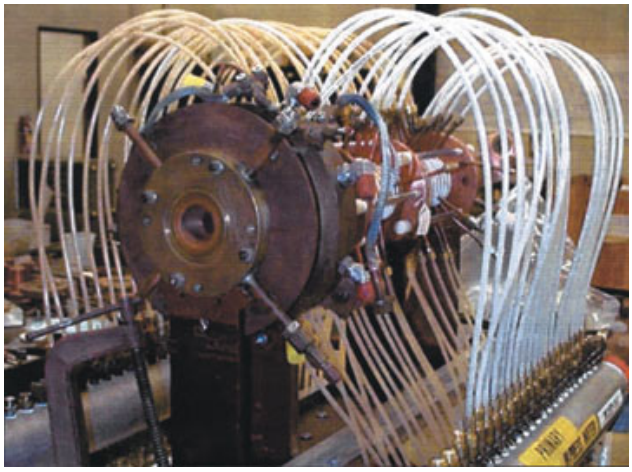
Cryogenic Biaxial Loads Facility



This facility, in the design phase, will be able to induce tensile loads of up to 1.0 million pounds in each axis onto a test article up to 10 ft square. By limiting the test article to 6 ft square, the environments from the Thermal Acoustic Facility may be combined with this facility to make a world-class facility capable of biaxial loads, acoustics, radiant heat, and cryogenic conditioning.

Hyperthermal Convective Test Facility

This facility is used to test the thermal and ablative response of materials that insulate the Redesigned Solid Rocket Motor (RSRM) nozzle. The gas compositions and temperature conditions representative of those encountered in the RSRM nozzle are simulated in this facility and used to develop and qualify new materials for flight.



Thermal Acoustic Facility

This facility was developed in 1997 for advanced space transportation thermal protection system and is capable of duplicating the key acoustic loading and surface temperatures environments of the X-33 hypersonic flight. The facility was modified in 1998 to double the acoustic energy to test Space Transportation System External Tank thermal protection system materials. At present, this facility can deliver radiant heat from 0 to 30 Btu/ft^2/sec and up to 172 dB onto a test article up to 6 ft square. Test articles can also be cryogenically conditioned.

Environmental Gas Laboratory (EGL)

The EGL routinely analyses all MSFC gases to ensure that specifications for use are met. This includes analysis for total hydrocarbons, moisture, particulates and other possible contamination found in breathing air, nitrogen, oxygen, helium and hydrogen used throughout the Center.

Propellants and Reactive Fluids Test Facility

The Propellants and Reactive Fluids Test Facility is available to test fuels, oxidizers, monopropellants and other reactive fluids for compatibility with various metallic and non-metallic structural materials. High-Test Hydrogen Peroxide (HTP) has been examined extensively using techniques associated with this facility.

Point-of-Contact:

Erin Richardson / ED36
(256) 544-2873
erin.richardson@msfc.nasa.gov

Manufacturing Services Facilities

Purpose:

To manufacture hardware for research, development, and space flight with high standards of quality routinely met for in-process inspection, certification, as-built configuration control, and flight hardware traceability.

Machine Shop Facility

The Machine Shop performs all in-house fabrication for the Center. This includes flight hardware, prototype construction, and feasibility review of concepts. The facilities include a sheet metal shop, a welding shop, a plating facility, electronics assembly, and a sand blast facility.

Sheet Metal Facility

The Sheet Metal Shop includes bending, shearing, bonding, cutting, drilling, rolling, tube bending, flex hose fabrication, and assembly work. The Sheet Metal Shop has 100k clean room facilities for both bonding and assembly operations.

Welding and Heat Treatment Facility

The Weld Shop contains various manual welding equipment for welding aluminum, mild steel, stainless steel, and refractory materials. The Weld Shop also has a completely CNC variable polarity plasmas arc (VPPA) welding system; a high vacuum electron beam welding system capable of welding components up to 1 inch thick under high vacuum; and a resistance seam welder capable of performing both continuous roll seam and single spot welds. The heat treating facility houses four heat treat furnaces ranging in temperature from 150 to 2000 degrees F. This facility also has endothermic and exothermic atmosphere generators, a 100-ton hydropress, two oil quech tanks, and one water quench tank. This facility provides heat treating processes for development, flight, and test hardware in support of all NASA enterprises.

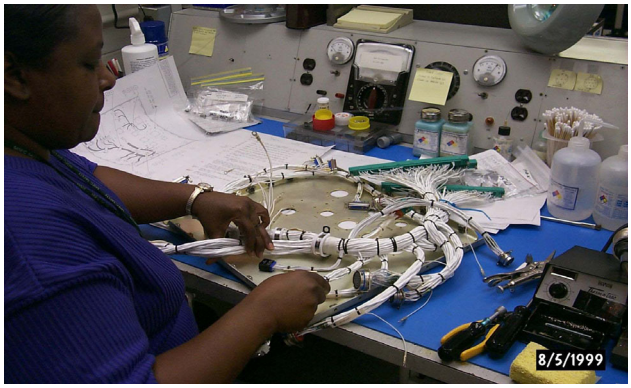
Point-of-Contact:

David McGaha / ED37
(256) 544-1031
david.mcgaha@msfc.nasa.gov

Manufacturing Services Facilities

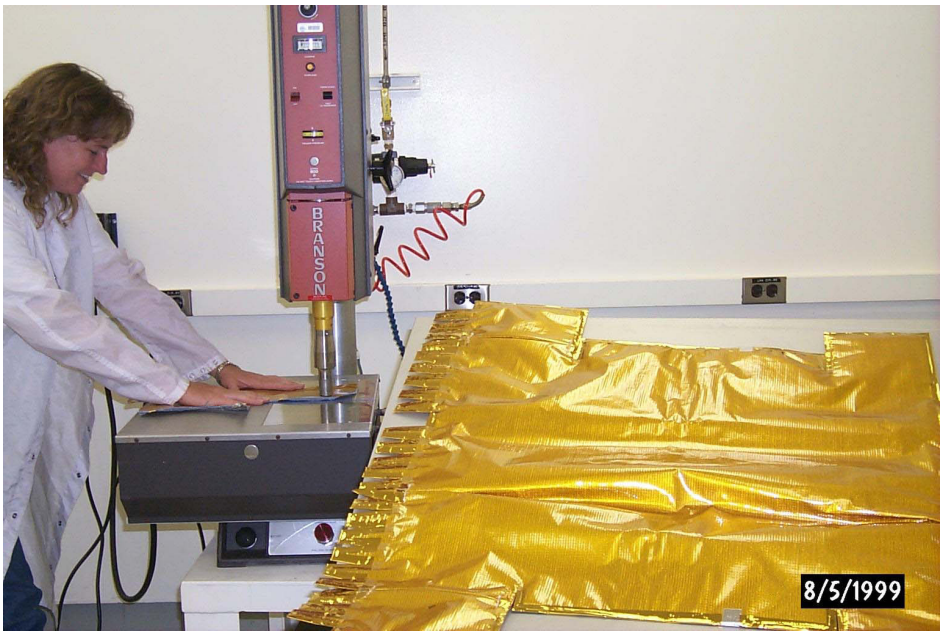
Surface Treatment Electroplating and Painting Facility

The facility for Surface Treatment, Electroplating and Painting houses a variety of tanks used for cleaning and degreasing hardware, chromate conversion coating and deoxidizing aluminum alloys, pickling and passivating stainless steels, and de-rusting and phosphating mild steel. In addition, this facility contains sand and bead blasting equipment. The plating facility can perform chrome, copper, bright nickel, sulfamate nickel, electroless nickel, cadmium, and gold plating. Also performed are types I, II, and III anodizing and dyeing of aluminum; electropolishing of stainless steel and copper alloys; black oxide coating of stainless steel and mild steels; and bright dipping and electrocleaning of various metals and alloys. The paint facility consists of two large and one small paint booths. They are used for priming and painting development, flight, and test hardware using various types of coatings such as polyurethane, epoxies, and enamels.



Precision Cleaning Facility

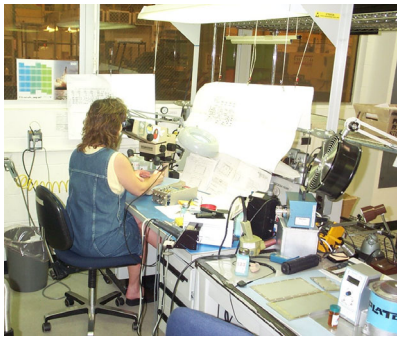
The Precision Cleaning Facility is used for processing hardware that requires a high degree of cleanliness. The strenuous requirements of MSFC-SPEC-164B, Class I, II, and III, Level A, B, or C, and MIL-STD-1246C, Level 250 to 1000. This facility contains three cleaning consoles capable of cleaning stainless steel and aluminum tubing up to 1.5 inches in diameter, an ultrasonic cleaner, three parts washers, one jet washer, one vapor degreaser, and one vacuum drying oven. This facility is classified as a 30K clean room.



Manufacturing Services Facilities

Electrical Shop

The Electrical Shop is housed in a 3,500 sq. ft. environmentally controlled work area used for fabricating and assembling electrical and electronic boards, boxes and cables. The shop contains a screen printer and solder reflow oven for soldering surface mount components on PC boards. Additional capabilities include coil and transformer winding, conformal coating, staking, plated thru-hole board soldering and electrical potting processes. Component identification is also performed in this area. This shop is used in the development and fabrication of flight and non-flight hardware in support of all NASA enterprises.



Precision Assembly

The Precision Assembly Shop is housed in a 2,800 sq. ft. 100K clean room environment used for assembling mechanical parts into completed mechanical assemblies and sub-assemblies. The assembly machinist receives precision cleaned and bagged parts and assembles the parts per detailed drawings and specifications using tools and fixtures as required. The precision assembly operation supports many NASA enterprises, the most recent of which has been the Environmental Control and Life Support System (ECLSS) and g-LIMIT projects.

Sandblast Facility

The Sandblast Facility consists of two structures; one of which is the blast building where the actual blasting takes place. The blast building is a two-sided shed approximately 45 feet wide and 60 feet long with a roof height of 19 feet. The other structure is a section of a Saturn V Rocket fuel tank, which has been converted to store the blast media and equipment. A diesel compressor operates the grit blaster and breathing air for the operator. The facility is used for various types of grit blasting media to meet specific requirements depending upon whether the parts will be surface treated, plated or painted. We have used sand, garnet, iron oxide, coal slag, steel shot, walnut hulls as a blasting media. This facility is used in the development and fabrication of flight and non-flight hardware in support of all the NASA enterprises.

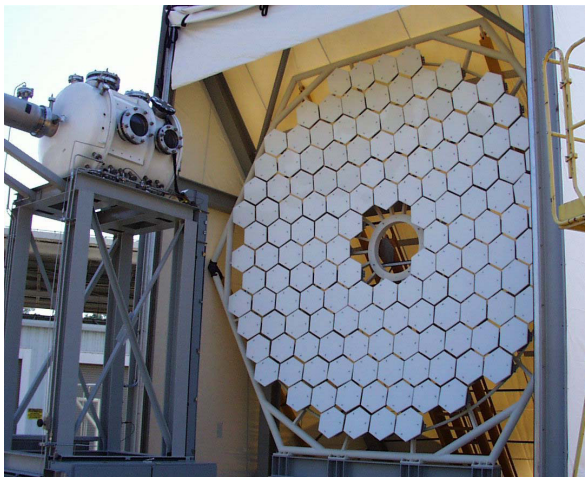
Point-of-Contact:

David McGaha / ED37
(256) 544-1031
david.mcgaha@msfc.nasa.gov

Special Test Equipment Design Facility

Purpose:

To design structures, hardware, or equipment intended to be used for testing or simulation, or associated with the manufacturing, process development, and preparation of MSFC facilities for testing or simulation.



Point-of-Contact:

Jay Medley / ED37
(256) 544-1085
jay.medley@msfc.nasa.gov